

TD
196
A25
A32
MOE
APIOS

ACIDIC PRECIPITATION IN ONTARIO STUDY

ANNUAL PROGRAM REPORT

FISCAL YEAR 1986/1987

APIOS REPORT NO. 005

A.P.I.O.S. COORDINATION OFFICE
ONTARIO MINISTRY OF THE ENVIRONMENT

JULY 1987

PROGRAM COORDINATOR: G.W. SCOTT

Copyright Provisions and Restrictions on Copying:

This Ontario Ministry of the Environment work is protected by Crown copyright (unless otherwise indicated), which is held by the Queen's Printer for Ontario. It may be reproduced for non-commercial purposes if credit is given and Crown copyright is acknowledged.

It may not be reproduced, in all or in part, for any commercial purpose except under a licence from the Queen's Printer for Ontario.

For information on reproducing Government of Ontario works, please contact ServiceOntario Publications at copyright@ontario.ca

ACIDIC PRECIPITATION IN ONTARIO STUDY
ANNUAL PROGRAM REPORT
FISCAL YEAR 1986/1987

APIOS REPORT NO. 005

A.P.I.O.S. COORDINATION OFFICE
ONTARIO MINISTRY OF THE ENVIRONMENT
JULY 1987
PROGRAM COORDINATOR: G.W. SCOTT



ACDY
TD / 196 / A25 / A32 / MOE / AP105

PREFACE

The Acidic Precipitation in Ontario Study was established in 1979. This multidisciplinary program is managed by the APIOS Coordination Office which:

- ° provides overall leadership and conducts the budget preparation and management for the program;
- ° provides secretarial support for the technical committees thus facilitating the transfer of information among working groups;
- ° provides guidance to the Communications Work Group in the development and implementation of the Ontario and U.S. strategy for dissemination of information;
- ° maintains a library of current information on acid rain;
- ° responds to public enquiries for information and coordinates responses when more than one Branch is involved;
- ° maintains coordination links with major studies in other provinces and countries;

Additional information concerning any of the activities described in this report may be obtained by contacting that Office at the following address:

APIOS Coordination Office
7th Floor
40 St. Clair Avenue West
Toronto, Ontario

(416) 323-5051

Mailing Address:

APIOS Coordination Office
Ministry of the Environment
Suite 100
135 St. Clair Avenue West
Toronto, Ontario
M4V 1P5

(Une version abrégée est disponible en français)

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	1
TASK #1 - ATMOSPHERIC PROCESSES STUDIES	3
A. Emissions Inventory	3
B. Modelling Studies.....	3
C. Deposition Monitoring Networks	5
D. Oxidants Strategy Development	5
E. Meteorological Studies	6
F. Laboratory Support and Quality Assurance ...	6
TASK #2 - AQUATIC EFFECTS STUDIES	7
A. Chemical Studies	7
i) Calibrated Watersheds	7
a) Chemical Limnology	7
b) Lake and Stream Models	7
c) Metal Contaminants	8
ii) Extensive Lake Sampling	8
B. Biological Studies	9
i) Algae	9
a) Filamentous Algae	9
b) Odour Production by	
<u>Chrysochromulina breviturrita</u>	10
c) pH Change and Algal "Fossils"	
in Lake Sediments	10
ii) Zooplankton	10
iii) Invertebrates	11
iv) Fish Studies	11
v) Biological Survey	16
vi) Biological Monitoring	17
vii) Wildlife Studies	17
C. Remedial Methodologies Development	18
i) Whole Lake Liming	18
ii) Liming of Spawning Shoals	20
iii) Future Work	20
D. Laboratory Support and Quality Assurance ...	20
TASK #3 - TERRESTRIAL EFFECTS STUDIES	21
A. Vegetation Studies	21
i) Lichen and Bryophyte Study	21
ii) Mobile Rain Exclusion Canopies	21
a) Soybean Yield Effect Study	21

TABLE OF CONTENTS (continued)

	<u>Page</u>
b) Multi-Year Study with the REC System to Determine Joint Effects of Simulated Acid Rain, Ozone, and Soil Nutrient Stress on Sugar Maples and White Spruce	22
iii) Greenhouse Experiments	23
B. Soil Studies	24
i) Baseline Studies	24
ii) Soil Variability Study	24
C. Forest Productivity and Decline Studies	24
i) Maple Decline Study	24
ii) Forest Growth Study	25
iii) Dendrochronology and Hardwood Decline Studies	25
D. Wildlife Studies	26
i) Cadmium Levels in Ontario Moose and Deer	26
ii) Relationship of Soil Acidification to Cadmium Levels in White-tailed Deer Forage and Pellets	27
iii) Cadmium Levels in Black Bears	28
iv) Indicators of Cadmium Exposure and Health Effects on Moose and Deer	28
E. Laboratory Support and Quality Assurance ...	28
TASK #4 - BIOGEOCHEMISTRY STUDIES	29
A. Biogeochemical Study Sites	29
i) Monitoring Programmes	29
ii) Data Workup Projects	30
a) Plastic/Harp Lakes	30
b) Hawkeye Lake	30
c) High Falls	31
B. Process Studies	31
i) Bioaccumulation of Nutrients	31
ii) The Effect of Acid Deposition on Natural Mineral Weathering Rates	32
iii) Aluminum Geochemistry in Catchments Stressed by Acid Deposition	33
iv) Sulphur Cycle Study	33
C. Laboratory Support and Quality Assurance ...	34
TASK #5 - SOCIO-ECONOMIC ACTIVITIES	35
A. Damages and Benefits	35
i) Financial Value Models Review Study ...	35
ii) Lake Algae Study	35
iii) The Value of Recreational Fishing	36

TABLE OF CONTENTS (continued)

	<u>Page</u>
B. Costs of Abatement and Mitigation	36
C. Strategy Development and Evaluation Tools ..	36
TASK #6 - LEGAL INITIATIVES	38
A. Provincial Initiatives	38
B. International Initiatives	38
TASK #7 - PUBLIC RELATIONS INITIATIVES	41
Muskoka '85 Conference	41
Countdown Acid Rain	41
Public Awareness Activities	41
SUMMARY	43
APPENDIX I - INTERNATIONAL LRTAP PROJECTS	46
APPENDIX II - BIBLIOGRAPHY	52

INTRODUCTION

In 1979, Ontario established the **Acidic Precipitation in Ontario Study (APIOS)** to investigate the causes and effects of the long range transport of air pollutants.

The program is organized into seven areas of work: emissions and atmospheric processes, aquatic effects, terrestrial effects, biogeochemical effects, legal initiatives, economic studies and information services. Each program area has its own specific goals and obtains its direction from an interbranch or interministerial Working Group. In addition, the credibility of the scientific research is assured by a documented and operational quality assurance program.

Recently, there has been mounting evidence of serious adverse health effects induced by pollutants involved in the formation of acid rain. The APIOS Coordination Office is compiling this information to obtain a more complete picture of the damages caused by acid rain.

Ontario is continuing to coordinate its research and emission control efforts with other parts of Canada and the United States since the solution to the LRTAP problem requires action by all jurisdictions involved. Appendix I provides a summary of international LRTAP projects in which MOE is involved. Appendix II provides a bibliography of APIOS related publications and technical reports.

In 1985, the Canadian provinces east of the Manitoba-Saskatchewan border and the federal government agreed to reduce SO₂ emissions by 50% from the 1980 base case to 2.3 million tonnes per year by 1994.

Ontario went beyond the commitment it made at the federal/provincial meetings. Its Countdown Acid Rain program (announced December 1985) will reduce Ontario's emissions from the 1980 base case level of 2,194 kilotonnes to 885 kilotonnes by 1994.

The new regulations are aimed at four corporate sources which together emit 80% of Ontario's SO₂. These sources are Inco, Falconbridge, Algoma (Wawa) and Ontario Hydro.

This package of emission controls was developed in consultation with each of the major pollution sources to ensure that economic activity need not be inhibited.

Control technology has not been specified and the individual companies may choose their method of abatement so long as the legal limits are met by the specified dates. The regulations provide for a three year research and development period, leading up to a final report by December 31, 1988 from each of the major sources. This report will spell out precisely how the emission limits

will be met. The semi-annual interim progress reports, required under the regulation, are being provided by the four major companies. These are reviewed by experts from various Ontario ministries. Based on the first two reports submitted, the government is confident that the companies are in compliance and on schedule.

However, the major emission reductions in Ontario and elsewhere in eastern Canada will not be sufficient to achieve the 20 kilogram target which will protect most of the aquatic ecosystems. Major emission reductions are also required in the United States. All Canadian attempts to negotiate a bilateral treaty on acid rain with the United States have failed to date. At the Summit meeting with the Prime Minister, the President reaffirmed his commitment to clean coal technology development and agreed to consider the possibility of an accord.

A number of initiatives were launched through the APIOS program in 1986/87 to increase awareness of acid rain in both countries and to stimulate American citizens to pressure for acid rain controls.

Ontario citizens are aware of acid rain and are educating themselves as evidenced by the number of requests made directly to the APIOS Coordination Office. Over 650 individualized packages of information were mailed out and 400 people visited the Office. These contacts are over and above the enormous quantity of requests for acid rain information handled directly by the Communications Branch.

It is hoped that Ontario's realistic and practical approach in severely limiting its own emissions will encourage the United States to take similar positive action.

A sound economy is dependent on a clean environment.

TASK # 1 - ATMOSPHERIC PROCESSES STUDIES

A. Emissions Inventory

The compilation of statistics on the production of SO₂, NO_x and other pollutants serves several purposes:

- A) Trends in emissions of acid-producing gases are determined and matched with changes in deposition patterns;
- B) Detailed information on SO₂ and NO_x emissions, by geographic locations is required by all of the atmospheric models;
- C) Knowledge of the location and magnitude of emission sources is also essential in planning cutbacks of acid gas emissions.

During FY 1986/87, the upgrading work on the Ontario Acid Rain Emission Inventory was carried out to provide more complete information regarding SO₂, NO_x and VOC emissions as well as related statistics. A full scale emission questionnaire survey of the major Ontario sources for the above pollutants was initiated in which companies are being asked to report their fuel consumption, production quantities, and if available, their stack emissions for the years 1985 and 1986. A project to compile alkaline dust and ammonia emissions information to be used as input to long-range transport models was also initiated near the end of the fiscal year.

A common emission estimation methodology for sulphur dioxide was established together with Environment Canada. Trend analysis of the preliminary 1984 and 1985 Ontario SO₂ data has indicated that there is a slight increase of sulphur dioxide from 1983. Such a trend is in agreement with the general economic recovery in the Province since 1983. However, the increase in SO₂ emissions, mainly from smelters, is partially offset by a reduction in the utility sector. Overall, there was a decrease in SO₂ emissions from 1980 to 1985. The 1984 U.S. power plant data from U.S. EPA NEDS was processed, standardized and used in limited analysis of U.S. emissions.

B. Modelling Studies

Mathematical models combine our knowledge of the movement of air masses and the scavenging and chemical transformation of pollutants during transport into a set of numerical equations. Output from the models can be compared to observed deposition patterns, and if the comparison shows a close agreement, we gain confidence that we have a good understanding of the causes and mechanisms involved in acid deposition. Once the models are sufficiently developed, emission reduction scenarios can be assessed by looking at resulting deposition patterns. The models can also be used for interpretation of data.

Two simple long range transport models, a statistical model and a trajectory puff model have been developed. The statistical model simulates long-term average deposition and air concentration, whereas the trajectory puff model simulates the same on a monthly and seasonal time scale. Both models were extensively evaluated, peer reviewed and used in the development of control strategies. The models have also been used in international studies such as ISDME (International Sulphur Deposition Model Evaluation).

A computer program, including gas phase and aqueous phase chemistry of the atmosphere, was developed to be used in the trajectory puff models. Evaluation and application of this program is continuing. A mesoscale wind model was also developed and tested and is being used in conjunction with the trajectory puff model to study the local impacts of major point sources.

A working version of the eulerian long-range transport model (ADOM) was installed at the CMC computer. The model was evaluated with OSCAR 2 and PEPE/NEROS data. Further evaluation of the model is continuing. The model results are being used to plan the joint U.S./Canadian field study to evaluate the ADOM (Canada) and RADM (U.S.) eulerian models. Once evaluated, the models will be applied to investigate the importance of non-linearity in sulphur deposition and to determine the most effective way to control emissions of SO₂, NO_x and hydrocarbons.

The eulerian model has also been installed at the University of Toronto's CRAY XMP computer. The severity of non-linearity of sulphur chemistry in the atmosphere, and the impact of emission reduction in Canada and the U.S. will be investigated using this computer during the fiscal year 1987/88.

A project to improve the cumulus cloud parameterization in the eulerian model was started in collaboration with Electric Power Research Institute and Environment Canada. An inter- comparison of the various modules of the model with NCAR model will be carried out as part of this project. The project is expected to last approximately three years.

The eulerian model is computer intensive and requires a super computer (such as CRAY) for efficient executions. To minimize the cost of running the model, a project was started to determine if a limited set of meteorological events could be used to simulate seasonal and annual average values. Results of this study will be evaluated in the coming months.

The primary future focus of model development efforts will be to evaluate and apply the eulerian model. The simpler statistical and lagrangian model development is essentially complete and will be used for emission control studies as the need arises.

C. Deposition Monitoring Networks

Deposition monitoring was continued across the province, with air and precipitation data being collected in the daily and 28-day networks. Internal audits of network operations were carried out, together with the analysis and reporting of routine QA/QC data.

Routine sampling for trace metals in both air and precipitation was initiated at Dorset. These data will assist in the apportionment of impacts due to large point sources, and in the evaluation of the effectiveness of emission controls in limiting acidic deposition.

Initial planning, site selection and equipment acquisition took place for Ontario's contribution to a large field study due to start in 1988. This field study is designed to provide data for the evaluation and validation of eulerian models of pollutant transport and deposition. Ontario's contribution takes the form of additional daily monitoring. Air and precipitation data will be collected at eight sites in Ontario, plus one intercomparison site in Quebec and a further intercomparison site in the U.S. Network data collection is expected to continue for two years, and will be supplemented by short-term intensive experiments.

Daily and cumulative network data for 1985 were reported, together with statistical summaries of the data. Trace metal sampling was described at the Conference on Advances in Spectroscopy and Laboratory Science in Toronto, October 1986, and a number of other papers have been prepared or are in preparation for presentation or publication during 1987.

D. Oxidants Strategy Development

Data from the Sarnia Oxidants Study were used as input to mathematical modelling runs, to investigate the effectiveness of hydrocarbons versus NO_x control in southern Ontario. Preliminary results indicate that control of hydrocarbons should be preferred, but this work is on-going. Conclusions are expected by the end of FY 1987/88.

Two papers on Ontario's oxidants program were presented at the North American Oxidant Symposium, Quebec, in February 1987.

The vehicle emissions testing program is continuing.

A progress report on Ontario's Oxidants Strategy Development was prepared in August 1986, and areas still requiring attention in order to complete the strategy development were identified. These are now being addressed.

E. Meteorological Studies

A meteorological data acquisition system (MDAS), capable of providing support for special studies and episode analysis, as well as modelling activities, has been implemented. MDAS is a computerized system which collects and stores meteorological data supplied by Environment Canada from the North American network of weather stations. Air parcel trajectories are also calculated by the system for interpreting event precipitation and other air quality data.

During FY 1986/87, meteorological data were acquired and archived on an on-going basis. Air parcel trajectories at various locations in Ontario and eastern North America were calculated and archived on a daily basis. As well, the daily synoptic weather patterns for various locations in Ontario were categorized and archived. Climatological compilation of boundary-layer statistics was also initiated.

Programs were developed to merge MDAS meteorological data and the data from the Ontario air quality monitoring network so that the two types of data may be analysed together.

A new user manual of MDAS was completed.

F. Laboratory Support and Quality Assurance

A total of 82,029 tests were performed on samples collected for the Atmospheric Processes studies.

The Quality Assurance office of the Laboratory Services Branch continued its representation on this working group. The Deposition Monitoring Network has a well-defined and routinely implemented Quality Assurance program. The Quality Assurance Office participates by supplying control samples for the event and cumulative networks and also the 28-day accuracy study. Special concerns such as bag tests and field blanks are also addressed. The quality of data utilized in the models is an ongoing concern.

TASK #2 - AQUATIC EFFECTS STUDIES

A. Chemical Studies

i) Calibrated Watersheds

a) Chemical Limnology

A set of 20 streams and 8 lakes in Muskoka-Haliburton has been monitored for periods ranging from 5 to 10 years in an attempt to measure the long-term effects of acid deposition on the chemistry and biology of these waters.

One of the study lakes, Plastic Lake, has been the focus of intensive monitoring over a period of six years. Its acidification rate has resulted in extensive damage to its aquatic biota. The acidification of this lake has been the result of the input of strong acids, not the result of naturally occurring acids. A four-fold decrease in alkalinity and a decrease of 0.2 pH units occurred despite a reduction in the deposition of strong acids over the period of study. Acidification was accompanied by a decrease in base cation content in the lake but not an increase in strong acid anion (SO_4^{-2}) concentration, indicating that there has been a deletion of available cations in the lake's catchment.

b) Lake and Stream Models

Data collected as part of the calibrated watershed studies have been used to develop and calibrate several models.

A lake model (FLASCH) has been utilized for sulphate, phosphorus and base cations.

The Birkenes-Storgama chemistry model developed for Norwegian streams was calibrated for several of the Harp Lake inflows and has been employed in making predictions about the effects of changes in sulphur deposition (increases and decreases) on the chemistry of other Harp inflows. The hydrologic component of the model is being modified.

Scientific groups in Norway, Great Britain, Canada and the U.S. have expressed interest in cooperating on further model development and applying the model to catchments in their countries.

These models can be used as both investigative and predictive tools. As investigative tools, they can be used to examine the efficacy of the scientific concepts being modelled. As predictive tools, they can be used to predict changes in pH or alkalinity as well as other parameters under different loading scenarios.

As additional data become available from the various monitoring programs underway, these models will be refined resulting in improved accuracy of prediction. They will thus be very useful for comparing the benefits of various abatement strategies.

c) Metal Contaminants

Acidified lakes tend to have increased mercury levels. A study is underway to identify the sources of mercury in sensitive areas and the relationship between mercury concentrations in water to levels in biota.

A new solvent extraction technique has been developed which is much more sensitive in its analysis of mercury in water. Samples of various biota in the vicinity of water sample sites are also being analysed for mercury.

The performance of this method is still being tested using spiked synthetic samples as well as a wide variety of water types collected from all seasons.

Data currently show that mercury concentrations are low in the spring (<5 ng/L) but some reach high levels in the summer or fall (50 ng/L). The concentration in brownwater streams is about ten-fold higher than clear streams.

ii) Extensive Lake Sampling

This program is carried out in cooperation with the Ministry of Natural Resources, and is designed to delineate the magnitude of Ontario's aquatic resource at risk due to acidification. The results of sampling 6,063 lakes in the province were published. It was found that 4% were acidified (alkalinity <0 ueq·l⁻¹) and further 15.4% were extremely sensitive (alkalinity >0 ueq·l⁻¹ and <40 ueq·l⁻¹).

The majority of the acidified lakes are in an elliptical area around Sudbury, stretching to the northeast and southwest of the city. However, an increasing number of acidified lakes are being identified in other areas of the province, including Algonquin Park, Muskoka-Haliburton, Algoma, and Parry Sound. Mostly, these acidified lakes are small headwater lakes, and their distance from point sources implicates long range transport of acids as the cause of acidification.

Many of the lakes close to the Sudbury smelters show signs of significant improvement related to declines in sulphur dioxide emissions. This is seen as a very encouraging result, since it demonstrates that abatement of sulphur dioxide will result in tangible improvements in the water

quality. The degree of improvement in the lakes in the Sudbury area was correlated with their proximity to the smelter. A subset of about 50 Sudbury area lakes is being sampled annually to monitor any ongoing trends.

Another result of the extensive lake survey has been the identification of three acidified lakes in Pukaskwa National Park, in northwestern Ontario. These are the first acidified lakes found in this region, and they are unique in Ontario since they appear to be going acidic under a fairly low rate of wet sulphate deposition. The first year's sampling of deposition indicates that the total sulphate deposition in the area is about 16 kg/ha·yr. An analysis of the water chemistry results indicates that sulphuric acids, and not natural organic acids, are responsible for the water acidity in these lakes.

Efforts in 1986/87 were concentrated on sampling lakes in the following two areas:

- small (1 - 10 ha) lakes in the Northeastern Region. This size class have been under represented in the previous surveys,
- 100 lakes were sampled in the Northwestern Region to provide baseline chemistry data on low acid deposition areas.

B. Biological Studies

i) Algae

a) Filamentous Algae

Lake acidification produces noticeable alterations in planktonic and benthic algal populations. In particular, some forms of filamentous algae are favoured by acidic conditions. Filamentous algae can colonize extensive areas of the littoral zone of acidified lakes and may reduce fish spawning areas, as well as constitute an aesthetic nuisance.

In 1986/87, annual algal mapping continued in Bowland Lake, Plastic Lake and Lake 302. Mapping was initiated on Lake of Bays. These efforts will follow changes in the algal populations.

The use of a questionnaire was investigated as an assessment tool to evaluate the extent of the algae problem based on cottager's perceptions. For a detailed description see Task #5 - Socio-Economic Activities.

b) Odour Production by Chrysochromulina breviturrita

No known new cases of lakewide odour were attributed to this species in 1986. Total odour episodes known for Ontario, and New England States equal 12 (1978 - 1986). C. breviturrita is now known from over 100 Ontario lakes. Analyses of 610 lake-year (about 500 lakes) data set was started to define general physical-chemical conditions of lakes containing this species.

c) pH Change and Algal "Fossils" in Lake Sediments

The study of algae and diatom communities in acid lakes has some interesting applications. Diatoms and some types of algae (chrysophytes) leave remains in the sediment which do not decompose. By carefully characterizing the diatom or chrysophyte communities in a number of lakes over a range of pH's, a "calibration" can be developed which relates the pH to community composition. This calibration can then be applied to the chrysophyte or diatom remains in a sediment core and the pH history of the lake can be reconstructed.

All analyses (diatoms + chrysophyte scales) have been completed on calibration lake set (surface sediment from 52 lakes). One additional low alkalinity lake was sampled in November, 1986 for inclusion in calibration set. Cores from Lady Lake, Raven Lake and two Pukaskwa Park lakes were sectioned and dated with ^{210}Pb methods. All diatom and chrysophyte scale analyses of core sections have been completed. Additional cores from Plastic and Clear Lakes were collected. Full (mixed period) chemical characterization of all calibration and core lakes was done by helicopter in November, 1986. Statistical analyses were begun.

ii) Zooplankton

Various studies are underway to determine the effects of acidification on zooplankton in Precambrian Shield lakes including intensive monitoring of plankton from selected lakes with specific characteristics, extensive monitoring of lakes along a gradient in pH and experimental manipulations to test hypothetical mechanisms responsible for observed zooplankton community alterations.

A comparison of data from a number of surveys confirmed that the biomass of the dominant Daphnia species is reduced after relatively modest pH depression.

Chaoborus abundance does not increase after acidification as previously suspected. Acidification may be accompanied by replacement of acid sensitive by acid tolerant species, e.g. Holopedium, and by an increase in rotifer biomass.

Rates of zooplankton recovery after neutralization of acid metal-contaminated lakes are slower than anticipated. Even though communities may change after pH increases, they do not necessarily recover attributes characteristic of non-acidic lakes.

After correction for differences attributable to nutrients, zooplankton biomass increases with increases in pH for lakes in the Dorset area.

iii) Invertebrates

The effects of short-term increases in Al and H^+ concentrations on aquatic invertebrates were studied in various field experiments using streams in the Dorset area (high acid loadings) and in the Experimental Lakes Area - ELA (low acid loadings). Invertebrate (mayflies and some midges) avoidance experiments demonstrated significant correlations with elevated H^+ and Al at ELA but not at Dorset. The macroinvertebrate consumers exhibited greater sensitivity to pH depressions at ELA than at Dorset, which suggests that organisms at Dorset have adapted to the elevated acid conditions.

Comparison of the Algonquin Park stream invertebrates collected 50 years ago with data collected recently (1984-86) is continuing. The same insect taxa are present in 1984-86 as were observed 50 years ago at locations where pH fluctuations were small (6.4 - 5.7) but at locations where large pH depressions are currently observed (6.4 - 4.9), many mayfly and stonefly taxa present 50 years ago were not recorded in 1984-86. These insect taxa are known to be intolerant to low pH. This loss of the acid-sensitive species indicates that poorly buffered surface waters in this region have undergone some acidification in the past 50 years. Although the results have to be analysed quantitatively, it appears that a decrease in biomass for some insects (mayflies) has occurred in the last 50 years, while for others (e.g. blackflies) increases in biomass are apparent.

iv) Fish Studies

In FY 1986/87, a manuscript on salmonid response to H^+ and Al was finalized for journal submissions, the experimental portion of a lab and field investigation of the annual pumpkinseed (Lepomis gibbosus) die off in Plastic Lake was completed and a synthesis of research highlights was presented and published as

part of the proceedings of the international symposium on Acid Stress in Aquatic Organisms held in Antwerp, Belgium.

In summary, MOE research on eggs and fry of native Ontario fish shows that H^+ is more important than Al as a toxicant and that three responses to Al are possible in laboratory tests. Joint action of H^+ and inorganic Al produced mortality at pH 4.4 - 4.8 and pH 4.2 for fry of lake trout (Salvelinus namaycush) and brook trout (S. fontinalis) respectively but Al toxicity required sublethal H^+ stress. Al asphyxiation was not observed in oversaturated solutions at pH 5.1 - 6.0 where concentrations were lower and toxicant flow faster than in previous tests. Al increased survival time of eggs and fry of salmonids during acutely lethal exposures at pH 3.5 - 4.2 and of adult sunfish (Lepomis gibbosus) at pH 3.5. Responses to H^+ and Al were enhanced in dilute water and single episode pulse exposures required unrealistic combinations of time and concentration to produce mortality.

Despite the apparent complexity of toxic mechanisms and modifying factors, it is obvious that H^+ is the master variable driving the response of fish to cultural acidification. Further research will refine definitions of effect levels in-situ and shed further light on physiological mechanisms of toxicity. It will not, however, change the fact that any human intervention that reduces H^+ loadings to acid-sensitive aquatic ecosystems will improve their ability to sustain reproducing populations of fish.

The following studies are being performed under the auspices of MNR's Fisheries Acidification Program.

- Factors Controlling Species Richness

The relationship between lake area, pH and other abiotic factors on the number of fish species found in Ontario lakes was investigated.

The influence of both lake area and lake pH on fish species richness is demonstrated for 2,900 Ontario lakes. Generally, large lakes contain more fish species than small lakes. Although lake area and lake pH are related over the pH range 5.2 to 6.8 (as pH declines so does lake area), when the influence of pH is controlled, it was found that the mean number of fish species increases by a factor of 1.6 for a ten-fold increase in lake area. The relationship is linear in the log-log form. Similarly, when the effect of lake area on

species number is controlled, the negative effect of pH values < 6.0 on fish species is statistically significant.

Multiple regression analysis using all lakes showed that lake area is the dominant factor influencing fish species richness, accounting for 18% of the variances in species number. Four other factors: total aluminum (highly correlated with pH), latitude, dissolved organic carbon, and elevation explained a further 16% of the variance. For lakes with pH < 6.0, pH is the dominant factor, explaining 21% of the variation in fish species number. An additional 20% of the variance is explained by elevation, lake area and dissolved organic carbon.

- Fisheries and Water Chemistry Surveys

The chemical sensitivity of walleye and smallmouth bass populations to acidic deposition was examined. Using data from field and laboratory studies, pH categories were defined to reflect the species' sensitivity to low pH. For both smallmouth bass and walleye populations, extirpation was likely at pH < 5.5. It is estimated that 2.3% (n = 57) of the smallmouth bass lakes and 0.3% (n = 12) of the walleye lakes in Ontario have pH below the threshold of 5.5. Estimates were also made of the number and percent of smallmouth bass (12.2%, n = 296) and walleye (2.0%, n = 80) lakes with low alkalinities (below 2.0 mg/l) and therefore in danger of future acidification. In 1987/88 the relationship between cyprinid distribution and lake water chemistry will be examined.

- Bioassays of Lake Trout

Studies were continued to investigate whether spring pulses of low pH water containing high concentrations of aluminum occur on natural lake trout spawning shoals in the Muskoka-Haliburton area with resultant detrimental effects on lake trout survival. The effects of shoal liming were also investigated.

In situ bioassays of lake trout eggs and fry were carried out at five Dorset area lake trout spawning shoals. Eggs and fry were incubated within natural spawning rubble, and in a limestone treatment. Mortality of young lake trout was monitored at each developmental stage. Water quality at the incubation sites was sampled throughout the winter and during spring snowmelt.

After ice-out in April, fry from the bioassay in acid sensitive Clear Lake were held on two spawning shoals in chambers containing zooplankton indigenous to the lake. These fry were able to begin exogenous feeding as indicated by the presence of zooplankton in the gut.

Data from experiments conducted during the past three winters will be synthesized in 1987-88.

- Behavioural Response of Lake Trout Embryos to Acidic Water

Locomotor activity of lake trout embryos in the later stages of yolk absorption were investigated in terms of whether they are able to avoid water with low pH and elevated Al. Poor swimming ability and preference for contact with the substrate appear to eliminate the possibility that these embryos will effectively avoid the acidic runoff water entering the rubble of spawning sites during snowmelt.

- Exploited Lake Trout Lakes

Studies are underway to quantify lake trout population characteristics in two small low alkalinity and exploited lake trout lakes in the Dorset area. Mark/recapture results from two years, and creel surveys ongoing since 1983 will allow estimates to be made of population size, biomass, mortality rates, and recruitment in two acid sensitive systems.

- Reproduction of Brook Trout in an Acidic Stream

Spawning time and location were determined for a natural population of brook trout in Chikanishing River (pH 5.7), a small river in Killarney Park. Brook trout spawned at a groundwater upwelling site (pH 6.7). During the first week of April, stream water declined in pH to 5.2. Emergence from the redds began after the acid pulse had passed. Toxicity tests were conducted in five lakes with a range of pH (4.84 - 5.64). Lethal pH thresholds for eggs, hatching embryos and free embryos were pH 5.1, 5.0, and 5.0 respectively. Estimated lethal thresholds for Al for the three early life stages varied from 0.20 - 0.25 mg/L. Periodic swimming surveys during the winter revealed that adult brook trout overwintered in high pH water in deep pools below the ground water recharge zone. The field studies to confirm the timing of emergence relative to pH depressions are continuing.

- Aurora Trout Reproduction and Rehabilitation

Historically, four lakes in the Temagami District were populated by aurora trout, but became too acidic to sustain the fish. Recently, water quality has improved and studies are underway to assess effects of acidic ambient conditions on survival and reproduction of reintroduced aurora trout.

Acclimation procedures were used to successfully reintroduce aurora trout into one of their native lakes. Fish were held for five days in an intermediately acidic lake (George Lake, pH 5.8). Surviving fish (54%) were then transferred to one of the aurora lakes (Whitepine Lake, pH 4.8) and held for 72 hours, during which time no mortality occurred. Unacclimated fish experienced 82% mortality during 146 hours in the acidic lake. The growth and survival of these and earlier plantings of fish will be followed to determine if aurora trout will reproduce under the very acidic conditions present in the native lakes.

- Loss of Largemouth Bass in Lady Lake

Anecdotal evidence indicated that Lady Lake supported a sport fishery for largemouth bass throughout the 1960's. Coincident with a decline in water quality (decreases in pH, increases in secchi depth) angler success decreased in the 1970's. No largemouth bass were captured in extensive netting surveys carried out in the 1980's. Studies are underway to determine if the decline of largemouth bass in Lady Lake could be attributed to acidification.

Survival rate of young-of-the-year largemouth bass held in Lady Lake for two weeks in the summer of 1986 was high. Breeding size adult largemouth bass were transferred into Lady Lake in the fall of 1986. The lake will be surveyed for nesting activity, egg deposition and brook stock survival in the summer of 1987.

- Survival, Growth and Mercury Content in Stocked Lake Trout in Acidic Lakes in the Sudbury Area

Lake trout have been reintroduced into approximately 20 Sudbury lakes to assess the effects of fish size, stocking season, and lake acidity, on survival and growth. Tissue samples of recaptured fish were analysed for seven metals including mercury to assess contaminant

accumulation. Stocked fish have survived in lakes with pH > 5.0. Good growth and survival occurs in the absence of large biomass of competitors within the pH range 5.2 - 6.0. Stocked fish had relatively low levels of Hg and other metals in muscle tissue. In at least one lake reintroduced lake trout have reproduced successfully. Analysis of age and growth material will be done in 1987/88.

- Mercury in Sport Fish

The relationship between body burdens of mercury (Hg) in sport fish and lake physico-chemical characteristics was examined focusing on those chemical parameters known to be related to acidic deposition. Previous studies have shown that at low pH there is an increase in the rate of formation of monomethyl mercury, a form of mercury rapidly accumulated by fish.

During the 1986/87 fiscal year factors affecting Hg uptake in smallmouth bass and lake trout were examined. Lake variables most correlated to mercury in smallmouth bass were: magnesium, conductivity, calcium, pH and alkalinity, in descending order of significance. For lake trout, the lake variables most correlated to mercury were: dissolved organic carbon, apparent colour, and lake area (also listed in order of significance). Multivariate techniques indicated that dissolved organic carbon was the best predictor of mercury in lake trout while pH, dissolved organic carbon, and latitude were the best predictors of mercury in smallmouth bass.

Further studies will examine similar relationships in other species including brook trout and yellow perch.

v) Biological Survey

Much of the concern over the anthropogenic acidification of Ontario lakes and streams has been directed at its adverse effects on sport fish. In recent years, however, it has become apparent that the most sensitive organisms are a variety of benthic invertebrates that form an important link in the aquatic food chain.

In order to identify the potential extent of these damages, a biological survey of softwater Ontario Shield lakes will be conducted.

The primary objectives of this survey are to identify aquatic invertebrates that may be sensitive to low pH, and to quantify their response to low pH as a function of lake chemistry.

During FY 1986/87, the survey design was developed. Approximately 100 lakes will be selected in the Muskoka-Haliburton and Experimental Lakes areas for a survey of littoral zone invertebrates. This survey will be conducted during FY 1987/88.

vi) Biological Monitoring

Several cases of local, abrupt species extinctions (e.g. Amnicola in Heeney Lake, Hyallolella in Plastic Lake) have been documented in the Muskoka-Haliburton area. It would appear that, in addition to H^+ sensitivity, certain life history characteristics lead to a high probability of extinction over a short period of time, even though the degradation of water chemistry may be slight. Therefore, depending on the species selected, a monitoring programme could detect population losses over a relatively short period of time.

During FY 1986/87, the monitoring programme was developed and designed for preliminary implementation in FY 1987/88.

Lakes with a range of sensitivity between < 5 ueq/L (ultrasensitive) to 80 ueq/L will be routinely sampled for species which are normally abundant, have short lifespans, and are believed to be sensitive to H^+ including gastropods, amphipods, Mysis relicta, crayfish, cyprinids, leeches, and possibly some insects.

This programme will assist in the assessment of the effects of long-term trends in lake and stream chemistry on aquatic biota.

vii) Wildlife Studies

a) Toxicity of Aluminum to Amphibians in Waters Containing Natural Organic Acids

Recent surveys of amphibian breeding ponds downwind from the Sudbury smelters have shown that a high percentage of these ponds have very low pH and high concentrations of aluminum. In a cooperative study with McMaster University, the mortality of different life stages of the leopard frog (Rana pipiens) was assessed over a pH range of 4.0 - 6.5 and an aluminum concentration range of 0 - 1,000 ug/L. Investigations were also carried out on the interaction of aluminum and natural organic compounds in relation to aluminum toxicity to amphibians.

Leopard frog (Rana pipiens) embryos were the life stage most sensitive to low pH, newly hatched tadpoles were intermediate in tolerance, while fully developed tadpoles were the most tolerant life stage.

Aluminum was moderately toxic to embryos, but only at pH greater than 4.6. At pH 4.2 and 4.4, aluminum alleviated pH toxicity. Aluminum was extremely toxic to newly hatched larvae at all pH's above 4.2; however, aluminum seems to have no adverse effects at pH 4.2. Fully developed tadpoles (three weeks old) were extremely tolerant to aluminum.

While free aluminum is toxic to amphibians, waters with natural organic compounds (humic, tannic acids, etc.) appear to have an ameliorating effect on Al and metal toxicity to amphibians. In situ toxicity tests and transplants are in progress in 1987 to verify laboratory observations in the field.

b) Cadmium Burdens in Waterfowl

This cooperative program among Trent University, Royal Ontario Museum and the Ministry of Natural Resources was established to determine the level of cadmium and its distribution in the common goldeneye. Cadmium levels in different age and sex classes of waterfowl will be examined. The measurement of cadmium levels in feathers as a reliable non-fatal field sampling technique for waterfowl is also being assessed. Implications for ingestion of these waterfowl by humans and other predators will be examined.

Results to date have shown feather cadmium levels higher by a factor of 10 than those reported in other published Canadian studies. A significant difference, at variance with most published findings, was also noted between sexes for the mean cadmium level in primary feathers. Continuation of these studies in 1987-1988 will correlate Cd feather levels in goldeneye and other species to internal body burdens of this metal.

C. Remedial Methodologies Development

i) Whole Lake Liming

Recognizing that lake neutralization is at best a temporary measure to delay or reverse the effects of acidification, Ontario is pursuing the development of lake neutralization expertise as a method of protecting and rehabilitating lakes. Even under the most optimistic of emission abatement scenarios, the significant reduction of acid inputs into many of Ontario's lakes is several years away. Lake liming may prove to be a feasible interim measure for the protection of important gene pools, or the rehabilitation of significant sport fisheries.

In August of 1983, the first of two whole-lake neutralizations occurred. Bowland Lake was neutralized with 85 tonnes of finely powdered calcite. The limestone was applied in August by a Canso water bomber, and the pH of the lake was raised from about 5.1 to approximately 6.8. Prior to neutralization, Bowland Lake water was toxic to lake trout. Yellow perch still existed in the lake in a numerous but stunted population. The indigenous lake trout and white sucker populations had disappeared in the late 1960's, and repeated efforts to stock the lake had failed.

After neutralization, fingerling, yearling and adult lake trout were introduced to the lake. Liming Bowland Lake resulted in significant reductions in the mortality rates for pre-eyed eggs, eyed eggs, hatched fry and caged fry relative to the reference lake.

However, total mortality levels on Bowland Lake, which had been significantly lower than the reference lake in the first two years after liming, have risen to where they are similar to the reference lake. This indicates a slight deterioration in the protective effect of liming.

Only two lake trout spawning shoals were active in 1986 compared to five in 1985. No fish were observed on shoals but egg deposition was documented.

The perch population has declined by 61% from last year and is now similar in size and biomass to pre-neutralization levels. The growth rate and condition of the perch in Bowland Lake have declined dramatically from last year.

The filamentous algae which had previously been quite numerous, virtually disappeared the year after liming. However, the population has been reestablished and biomass is back to preliming levels, although there has been a marked change in species composition.

The second whole-lake neutralization occurred in May, 1984. Trout Lake, near Parry Sound, was a low alkalinity lake, with a self-sustaining trout population. The liming of Trout Lake demonstrated no adverse biological effects associated with lake liming. No significant mortality occurred in lake trout or in rainbow trout suspended in cages around the lake during the liming operation. Assessments of the fish community were made in 1986 and no changes were observed.

ii) Liming of Spawning Shoals

Preliminary experiments investigated the feasibility of treating lake trout spawning shoals with crushed limestone. In acidic Laundrie Lake, near Sudbury, incubation of lake trout eggs/sac-fry within plots of natural and limestone rubble showed improved survival in the limestone plots. Supporting behavioural studies in non acidic Miskokway Lake, near Parry Sound, indicated that spawning lake trout do not avoid natural shoals artificially covered with limestone. Expanded studies are planned for 1987/88 to more thoroughly assess mortality and water chemistry.

On the basis of the positive results to date, site-specific shoal liming offers considerable promise as a mitigative technique - both as an additional protective measure in conjunction with whole-lake liming, or as the sole measure required in lakes where water quality problems occur only during spring runoff. An obvious advantage of shoal liming is its much reduced scale, and lower cost in comparison to whole-lake neutralization. Potentially, shoal treatments may also exhibit longer duration than whole-lake applications.

Completion of these studies should identify the feasibility and expected benefits of shoal liming as a mitigative technique for Ontario lakes.

iii) Future Work

A five year followup study was contracted out in 1986/87 to answer more questions and obtain important management information. This additional study will permit comparison of observed chemical trends with patterns predicted on the basis of reacidification models and will provide insight on early biological changes during the reacidification of neutralized lakes. Further studies will also examine the feasibility and benefits of shoal liming.

D. Laboratory Support and Quality Assurance

The total Water Quality Section testload for Task 2 during fiscal year 1986/1987 was 143,770 tests.

The Inorganic Trace Contaminants Section performed a total of 22,168 tests for Task 2 in fiscal year 1986/1987.

TASK #3 - TERRESTRIAL EFFECTS STUDIES

A. Vegetation Studies

i) Lichen and Bryophyte Study

Lichens obtain a substantial portion of their nutrients from the air and from precipitation. Since their chemistry reflects concentrations and deposition of atmospheric elements, they have been used as air quality indicators.

Lichens and mosses have been obtained and chemically characterized from approximately 50 locations across Ontario. Variability in chemical composition at given sites and during the growing season have also been determined. Interspecific comparison of chemical content between two lichen species has revealed close similarities, while significant differences have been observed between lichens and mosses.

Metal levels in lichens are strongly influenced by their proximity to major sources of metal-contaminated particulates. The sulphur content of lichens exhibits a south-to-north decrease in concentration. The elemental composition of wet deposition can account for only part of the variability seen in the chemical content of lichens. Gaseous and airborne particulate materials and perhaps the chemistry of the substrate, may also be required to account for the remaining variability.

Other activities under the Lichen and Bryophyte Study included inventories of species at three biological sites (see Task 3C) and the establishment of photometric plots of lichens to determine growth rate.

A draft of the final interpretative report was reviewed and the final version is due early in FY 1987/88. Voucher specimens of lichens and mosses from across the province have been deposited in the herbaria of regional and ARB offices.

ii) Mobile Rain Exclusion Canopies

a) Soybean Yield Effect Study

A fully automated rain exclusion canopy (REC) system is being utilized at the MOE phytotoxicology laboratory in Brampton to assess the impact of acid deposition and ozone on agricultural crops as well as commercially valuable forest trees. The system consists of three, mobile greenhouse shelters which

exclude ambient rainfall and apply simulated acid rain (SAR) treatments to test plants established in field plots. All aspects of the field system are controlled by a microcomputer and data acquisition system. In addition, elevated ambient levels of gaseous pollutants (e.g. O_3 , SO_2 , NO_x) are reduced in field plots via an air exclusion system consisting of large blowers, potassium permanganate-treated alumina filters and perforated polyethylene tubes. Gaseous pollutants such as ozone can be injected into the treatment plots via the blowers.

As in 1985, the REC system was utilized to determine the effects of SAR treatments (pH 3.07, 3.19, 3.35, 3.60, 4.30) and ozone on Hodgson soybean as measured by seed yield (kg/ha), seed weight, number of pods per plant, number of seeds per pod, number of seeds per plant and plant height. Statistical analyses of the harvest data indicated that there were no significant yield effects. The results of the two year study with Hodgson soybean will be published in 1987.

Scientists from the "Institut für Produktions und Ökotoxikologie", Braunschweig, West Germany cooperated with MOE staff in this study. Soybean leaf samples were collected from test plants in the REC system plots, were freeze-dried and sent to Germany for biochemical analyses of:

- a) proline content,
 - b) sugar content (fructose, glucose, saccharose), and
 - c) activities of enzymes - peroxidase, glutamase, dehydrogenase, acid phosphatase, superoxide dismutase.
- b) Multi-Year Study with the REC System to Determine Joint Effects of Simulated Acid Rain, Ozone, and Soil Nutrient Stress on Sugar Maples and White Spruce

During the spring of 1986, 1,500 sugar maple transplants from the Dorset area and 1,500 white spruce seedlings from the MNR Midhurst nursery were potted in mineral soil from a site near the Leslie Frost Centre and were placed in establishment plots in the field next to the mobile rain exclusion canopies. A shade cover was erected over the sugar maple plots to provide 40% shade to the trees. The plots were irrigated and weeded throughout the summer of 1986. The most vigorous individuals will be transferred to the treatment areas under the REC system in the spring of 1987.

For each of the three canopies, potted sugar maple and white spruce seedlings will be placed in various plots and subjected to ozone and SAR treatments over the entire growing season. Several non-destructive measurements will be made on the seedlings:

1. visible injury rating,
2. photosynthesis rates,
3. bud analysis (frost hardening in spruce buds),
4. throughfall and soil leachate chemistry,
5. plant height, stem diameter, leaf number, leaf dimensions, and
6. chlorophyll analysis of leaf disks.

Destructive measurements will be made on selected seedlings to investigate:

1. internal changes in cell size and shape,
2. physical and chemical changes in roots, and
3. mycorrhizae.

Researchers at the MNR Ontario Tree Improvement and Forest Biomass Institute in Maple, Ontario expressed interest in cooperating in the study. They will provide MOE with fast growing poplar hybrid cuttings which can be transplanted to the treatment plots along with the potted maple trees to provide shade and reduce wind in the plots. The poplars will be useful in standardizing photosynthesis measurements with the Licor 6200 photosynthesis analyser which was recently purchased for this study.

iii) Greenhouse Experiments

An indoor greenhouse experiment (initiated in 1985) was repeated to investigate the joint effects of simulated acid rain and gaseous pollutants on the growth and yield of potted Hodgson soybean plants. Plants were exposed to six SAR treatments and three ozone treatments in rain chambers and fumigation chambers respectively. Results suggest that plant biomass is reduced by ozone but not by simulated acid rain.

The second phase of an indoor experiment with potted radish plants was conducted to determine the effects of simulated acid rain application (frequency, duration and acidity) on dry shoot and dry root biomass. Results suggest that all three variables play a role in foliar injury and reduction of biomass.

B. Soil Studies

Baseline Studies

This study was designed to document changes in soil due to acidic deposition. Since 1980, over 400 soil baseline sites have been sampled across Ontario. In FY 1986/87, five soil sites, originally sampled in 1980, were resampled in order to monitor changes in soil properties which may have been caused by acidic precipitation. Editing and compiling of baseline soil data collected in 1982-83 were undertaken in FY 1986/87. A second report on the Soil Baseline Survey will be prepared to complete this soil database.

C. Forest Productivity and Decline Studies

i) Maple Decline Study

This study was initiated in 1984 to determine the role that acidic deposition is playing in the decline of woodlots being managed for maple syrup production in the Muskoka/Haliburton area of Ontario. Permanent observation plots were established to assess tree condition and each of the 8 woodlots were intensively sampled. A report on the results of the 1984 sampling program was published in FY 1985/86 indicating that acidic deposition was an additional stress to the severe epidemic of forest tent caterpillar in the late 1970s, combined with spring droughts in 1976, 1977 and 1983. Armillaria mellea, tree age and site management also were contributing factors.

In 1985/86, all plots established in 1984 were re-assessed for changes in tree condition. An additional three sites were sampled; one in Algonquin Park in an unmanaged stand, and two near Peterborough on calcareous, well-buffered soil. The results of the 1985 field investigations will be compiled in a final report in FY 1987/88.

A joint OMAF/MOE questionnaire was distributed to 600 Ontario Maple Syrup Producers Association members to ascertain their perception of the decline problem in their own woodlots. Fifty percent of the members responded. Of those, 1/3 felt that there was a decline problem in their woodlots. Decline was most common amongst producers in Prescott and Elgin Counties and in the Parry Sound District. However, there were no consistent geographical trends in decline severity across the province.

ii) Forest Growth Study

Concern has been raised by studies in the United States and Europe that acid deposition and other air pollutants may play a role in the reduction of tree growth rates.

This tree growth study is being conducted by the University of Toronto's Faculty of Forestry with APIOS funding. It is a continuation of a study which began in 1962. Originally, trees were tagged and measured on a number of lots in the vicinity of Dorset. The trees were remeasured in 1972 and again in 1983 and 1984. This unique record provides an opportunity for a detailed analysis of tree growth and stand dynamics and attempts to examine the effects of acidic deposition on these features. Factors including climate, disease, disturbances, site condition, tree age and competition all must be evaluated and quantified before air pollution stresses can be interpreted. An effort to index individual tree competition stresses was a major field activity during the summer of 1985. Trees in the study plots were assessed for competition by neighbours using angle of influence measurements.

This study was concluded at the end of FY 1986/87 and a final report is due early in FY 1987/88.

iii) Dendrochronology and Hardwood Decline Studies

The dendrochronology study of sugar maples is designed to determine whether growth decline is occurring across the province within three forest sectors. Fifty-four plots have been sampled both destructively and by extracting increment cores. Data analysis using the Tree Ring Increment Measurement (TRIM) System has been performed over FY 1986/87. Ultimately, these growth chronologies for sugar maple trees in Ontario will provide valuable baseline information for examining future changes in forest growth.

In FY 1985/86 and FY 1986/87, a contract was awarded to determine the incidence and severity of hardwood decline across the province and to establish growth chronologies for sugar maple in the province. A survey of sugar maple stands has been conducted by establishing 110 permanent observation plots across the province. Each tree within the plot was assessed according to the amount of dead branches, chlorosis and undersized leaves in the crown and given a decline rating. Data from this survey indicate that decline indices follow climatic (temperature) isoclines, increasing as one moves northward with the exception of the southernmost part of the province.

D. Wildlife Studies

i) Cadmium Levels in Ontario Moose and Deer

Environmental contamination by toxic metals, such as cadmium, and accompanying effects on wildlife and man are of increasing concern in Canada and other parts of the world. Cadmium occurs naturally at low levels in the ecosystem but the levels have increased due to atmospheric emissions from mining and smelting operations and from the combustion of fossil fuels. Recently, concern has been expressed that geographic regions characterized by poorly buffered soil may have higher levels of cadmium because of accelerated leaching due to increased acid precipitation.

The metal concentrates in some organs of longer-lived species such as moose and white-tailed deer, and may be toxic to human consumers at high levels of exposure.

In 1984, a preliminary study by MNR raised concern about cadmium levels in wildlife in Ontario when it revealed cadmium concentrations in samples of moose tissue from the Huntsville site two to three times higher than those found in Sweden. The 1985-1986 study examined the levels of cadmium in the kidney, liver and muscle of moose and deer in Ontario. Muscle samples were taken as an added precaution because of concern for public health. Objectives were to: determine the levels of cadmium in tissues of moose and deer in Ontario, determine regional differences in cadmium levels in moose and deer, examine the reasons for these differences and assess the implications of consumption of cadmium-contaminated animals by humans and other predators.

Results showed levels of cadmium in Ontario moose are comparable to or higher than those found in Quebec and were considerably higher than those found in Manitoba, Maine and Scandinavia. Concentrations of cadmium in moose were highest in kidney, decreasing in liver and often undetectable in muscle tissue. Cadmium levels in moose kidneys differed among sampling sites throughout Ontario. The highest levels were seen in both the area in and around Algonquin Park and St. Joseph Island, both sites where the annual wet deposition of cadmium is high relative to other areas sampled.

Cadmium levels in the tissues of deer were consistently lower than in moose, probably a result of the different dietary habits of deer which consume less cadmium-rich aquatic vegetation and more annual plants than moose. The non-buffered Loring site was

significantly higher in overall deer kidney cadmium levels than either of two buffered sites (Huron and Manitoulin).

Geochemical sensitivity of the soil and bedrock may increase the mobilization of cadmium in the environment. However, other factors such as plant species composition, local areas of high soil cadmium or proximity to atmospheric contaminants may also play a role in the contamination of wildlife.

In 1987, cadmium accumulation in the aquatic and terrestrial forage of moose will be examined. In addition, the relationship between cadmium contamination of forage, soil and bedrock characteristics will be assessed. Results will be correlated with OMNR analyses of cadmium levels in moose tissues from the same area.

ii) Relationship of Soil Acidification to Cadmium Levels in White-tailed Deer Forage and Pellets

This cooperative program between Laurentian University and MNR has been set up to determine cadmium levels and pH of surficial soils in deer yards designated as either geophysically sensitive (non-buffered) or tolerant to acid precipitation (buffered). It is also designed to relate cadmium burdens in surficial soils to levels present in major forage species of deer, and to assess the use of deer fecal pellets as bioindicators of the availability, exposure level and/or body burden of cadmium.

Results to date have shown higher pellet cadmium levels in the non-buffered deer yards than in the buffered yards. Work in 1987 will correlate cadmium burdens of forage, pellets and soil with cadmium body burdens accumulated by resident deer.

iii) Cadmium Levels in Black Bears

Black bears may be vulnerable to cadmium contamination because a large portion of their diet consists of vegetation. The cadmium biomonitoring program was expanded in 1987 to include a limited sampling of bear tissue in order to establish cadmium levels in bears and appropriate guidelines for human consumption.

iv) Indicators of Cadmium Exposure and Health Effects on Moose and Deer

The relationship between levels of metallothionein (a metal-binding protein) in the liver and kidney of moose will be examined through a cooperative program with University of Western Ontario. Metallothionein may prove to be useful as an indicator of cadmium exposure in wildlife.

The effects of cadmium contamination on the health of wildlife populations will be assessed by determining possible morphological damage in kidney and liver of moose and deer with high cadmium levels.

E. Laboratory Support and Quality Assurance

Water Quality Section performed 1,458 tests associated with Task 3 and 1,510 were performed by Inorganic Trace Contaminants Section.

During the fall of 1985, the soils lab was transferred to Dorset to handle the APIOS soils work and a low-level special fluoride workstation was set up. A new lab trailer and analytical equipment (atomic absorption spectrograph and an ion chromatograph) were fully operational by June 1986.

With the special analytical requirements for low-level metal analysis in Dorset, a clean room (Class 100) was required. Construction of the facility began early in 1986 and new analytical instrumentation was purchased (two ASV units, one with an autosampler). The clean room was fully operation by fall, 1986.

Implementation of a national quality assurance program for terrestrial effects monitoring studies was initiated in FY 1986/87. The objectives of this program are to standardize field and laboratory methodology, where possible, between agencies and to ensure data quality for terrestrial effects studies.

TASK #4 - BIOGEOCHEMISTRY STUDIES

A. Biogeochemical Study Sites

i) Monitoring Programmes

The biogeochemical monitoring programmes were continued during FY 1986/87 at the following sites: Plastic and Harp Lakes in south central Ontario and Hawkeye Lake in northwestern Ontario. The monitoring programme at the High Falls site near Sudbury was discontinued. These sites have been established in order to investigate the interaction between deposition, vegetation, soils, ground and stream water.

The Hawkeye Lake site near Thunder Bay is representative of a low deposition area (annual wet sulphate deposition is approximately 10 kg/ha·yr). The programme in FY 1986/87 included monitoring at the following installations:

- a meteorological station;
- a heated streamflow gauging station;
- standpipes for ground water monitoring;
- tension and zero-tension lysimeters;
- soil suction tensiometers;
- chemical sampling stations along open-water streamflow channels and at soil water seeps;
- leaf and twig litter decomposition stations.

The two southern Ontario sites are representative of a high deposition area (annual wet sulphate deposition is approximately 30 to 35 kg/ha·yr).

The monitoring programme at each of these two sites included data collection at the following on-site installations:

- meteorological/precipitation chemistry stations;
- heated streamflow gauging stations;
- tension and zero-tension lysimeters;
- soil suction tensiometers;
- chemical sampling stations along open-water streamflow channels and at soil water seeps.

At the southern sites, the leaf litter study has been completed.

Throughfall and stemflow monitoring studies were completed at all three sites. Emphasis is now on:

- a) soil water monitoring using zero tension lysimeters and tension lysimeters, and
- b) to relating the lysimeter data with the stream chemistry data.

The monitoring programmes are scheduled to continue at all three sites for FY 1987/88.

ii) Data Workup Projects

a) Plastic/Harp Lakes

The effect of acid precipitation on the biogeochemistry of these two contrasting forest ecosystems in the Muskoka-Haliburton area has been under investigation since 1981.

Since the initiation of the study, various data have been collected at Harp 4 and Plastic 1 (subwatershed sites) including:

- i) data on forest inventory and elemental composition of components of selected harvested trees to be used for the estimation of standing crop biomass and bioelement content of the standing crop in the study watersheds,
- ii) data on the physical and chemical properties of the soils in the study watershed to be used in the classification and estimation of soil nutrient reserves,
- iii) data on litterfall, and
- iv) data on leaf-litter decomposition.

During FY 1986/87, these data were worked up and analysed by an external contractor. Data reports were prepared and submitted for all of the above areas. In addition, an experimental design for estimating annual bioelement accumulation was prepared by an external contractor.

This information is vital for the modelling of the effect of acid precipitation on biogeochemical cycles and lake acidification processes in the Muskoka-Haliburton area.

b) Hawkeye Lake

The biogeochemical monitoring programme at the Hawkeye Lake site, about 40 km north northwest of Thunder Bay, has been underway since 1983.

In FY 1986/87, a contract was awarded for the workup and preparation of data reports in the following areas:

- field procedures manual;
- incident precipitation and deposition studies;

- grove throughfall and stemflow studies;
- stream water, ground water, snowpack and lake studies;
- forest inventory and biomass/bioelement standing crop;
- soil mapping, classification and nutrient/element inventories;
- litterfall studies;
- litter decomposition;
- soil leaching experiment.

Again this information is vital for the development of biogeochemical and lake acidification models.

c) High Falls

All studies at the High Falls site near Sudbury were terminated on March 31, 1986.

A contract was awarded in FY 86/87 to verify and tabulate all data collected at the site since its establishment in 1983. This project was not completed by the end of the fiscal year and will have to continue into FY 1987/88.

The information collected at this site will be of use in modelling the effects of acid precipitation at a medium deposition loading location (annual wet sulphate deposition of 20 kg/ha·yr).

d) Throughfall and Stemflow Data Workup

In addition, data generated by three and a half years of bulk incident precipitation, throughfall and stemflow collections at Plastic and Harp Lake watersheds have been undergoing intensive validation and review. This work will continue in FY 1987/88 with an analysis of the effect of tree species, season, storm intensity, length of preceding dry period, etc. on the chemical composition and flux in throughfall and stemflow. Comparisons with similar data from the High Falls and Hawkeye Lake sites will attempt to interpret the role of differences in atmospheric deposition on the throughfall and stemflow processes.

B. Process Studies

i) Bioaccumulation of Nutrients

The annual increment of basic cations, N, S, and P in the upland forests ecosystem including major tree species, litter and organic soil components will be measured for the Harp, Plastic and Hawkeye Lake study areas.

Using these data, the rate of proton production by forest growth will be calculated from the net difference in anion and cation assimilation and compared to rates of proton loading by atmospheric deposition, and proton consumption of abiotic soil processes. The standing crop measurements will then be compared between stands, with other forest stands in different deposition zones, with known nutritional requirements of the major tree species, and with soil content and availability.

This study will assist us in assessing whether current rates of nutrient uptake are sufficient or insufficient to maintain normal forest productivity, and whether acid deposition is affecting these rates.

ii) The Effect of Acid Deposition on Natural Mineral Weathering Rates

This project will assist in defining the interactions between various components of the terrestrial system and components of the aquatic system.

The project is being conducted by Prof. Nesbitt at the University of Western Ontario. MOE staff will assist in selecting a suitable study catchment.

The first phase will involve four activities:

- identification of weathering reactions in the catchment;
- major element mass balances and rates of reaction;
- behaviour of trace elements in the catchment;
- surface studies.

The second phase will include:

- experimental studies with strong, weak and organic acids;
- comparative study of catchment waters and experiments.

A kinetic-thermodynamic model will be developed to simulate weathering of minerals and rocks in different environmental settings and under different physical and chemical conditions.

The mineral weathering information will be incorporated in the models of long-term changes in stream chemistry to determine the rate of acidification in the Muskoka-Haliburton area.

iii) Aluminum Geochemistry in Catchments Stressed by Acid Deposition

Acidification increases aluminum levels in aquatic systems. This project will help define the sources and mechanisms for the increase in aluminum.

Previously developed analytical methods for speciating aluminum in stream samples are being modified for use on soil leachates. A manuscript comparing an automated aluminum speciation method with our older method has been completed.

The hypothesis that differences in bulk soil extractable aluminum are translated into differences in soil solution aluminum chemistry is being tested by comparing the soil solution aluminum chemistry of Harp and Plastic catchments (which have significantly different bulk soil aluminum chemistry). This information will allow us to determine the soil horizon that is the source of the aluminum.

Mineralogical differences between Plastic and Harp Lake soils are to be investigated in laboratory leaching experiments designed to identify which compounds are dissolving into solution giving the high aluminum levels.

iv) Sulphur Cycle Study

Information on the sulphur cycle is key to both the aquatic and biogeochemistry components of the APIOS programme.

This study has the following objectives:

- to determine the extent that sulphate adsorbed to soil Fe and Al oxides is a major sink in upland forest soils;
- to determine the extent that sulphate is incorporated into upland forest biomass relative to that adsorbed in the mineral fraction of upland forest soils;
- to determine the saturated sulphate retention capacity;
- to determine effective rate constants for catchment sulphur uptake and release as a function of deposition rates;
- to determine the extent that mineral weathering is releasing authigenic sulphur as sulphide.

Work to date has indicated that water soluble sulphate is found mostly in the upper organic horizons, whereas adsorbed sulphate is primarily in the B horizons. Effective rate constants for catchment sulphur uptake and release as a function of deposition rates will be used in the long-term catchment acidification model.

C. Laboratory Support and Quality Assurance

Water Quality Section performed 70,475 tests and Inorganic Trace Contaminants Section performed 12,090. Developmental work at the Dorset lab consisted of optimization of the Anodic Stripping Voltametry methods for the analysis of ultratrace levels of metals in surface water. Methods are now on line for zinc and copper using the Hanging Mercury Drop Electrode technique and for lead by the Rotating Disc Electrode method.

In the summer of 1986 further work was done on soluble and adsorbed SO_4 in Dorset soils. The procedure for adsorbed SO_4 was refined and put on line.

TASK #5 - SOCIO ECONOMIC ACTIVITIES

A. Damages and Benefits

i) Financial Value Models Review Study

In 1980-81, the Ministry commissioned the development of computer models that could be used to estimate the biophysical effects of acid deposition in Ontario. Models were developed for commercial fisheries, forestry, agriculture, materials and commercial furs.

A critical review of the following three models was undertaken: forestry, agriculture and materials corrosion. A consulting group was retained to review the structure and logic of these models and propose such revisions as necessary to update them.

The work has been completed and a report with the consultant's recommendations for revising the models is now available. Model revisions will be carried out in FY 1987/88.

ii) Lake Algae Study

Recent evidence suggests that acidification has resulted in the increased growth of:

- a) filamentous algae which can form slimy, unpleasant aggregates in nearshore areas and
- b) Chrysochromulina breviturrita which produces a rotten cabbage-like odour.

A two-year study was undertaken to determine the incidence of these algae and their effects on lake use.

The Ministry developed an innovative survey approach to sample a limited number of lakes and the results were then extrapolated to generate accurate estimates of algae conditions for the entire region.

A pilot study, conducted in 1985 on ten lakes for which the Ministry had reliable data on algae presence, demonstrated that cottagers' perceptions could be used to accurately identify the presence of both types of algae.

The main survey was undertaken in 1986 and included over 5,200 cottagers on 204 lakes in the Districts of Parry Sound and Muskoka, the County of Haliburton, small adjacent portions of Nipissing District and the Counties of Victoria and Peterborough.

The study found that some or considerable filamentous algae were present in 48% of central Ontario lakes, while odour-producing algae were present in only 6% of these lakes. Lakes in Muskoka have a somewhat higher incidence of both filamentous (54%) and odour-producing (12%) algae. A definite relationship between the presence of algae and acid sensitivity of the lake was found, although a cause and effect link remains to be established.

Not surprisingly, almost all cottagers who reported algae in their lake expressed concern about it. A substantial number of cottagers indicated that both types of algae affected their general enjoyment of their lake as well as specific activities (e.g. swimming and boating). Most cottagers considered the algae to be as serious as other lake-related problems, such as acid rain, declining water quality and too much recreational activity.

iii) The Value of Recreational Fishing

The recreation use of many Ontario lakes is impaired by water quality problems such as acidification, eutrophication, or contamination. These problems can lead to loss of economic value or enjoyment by recreationists, and to loss of economic activity or sales by the recreation service sector.

A consulting company was retained to conduct a study of the beneficial consequences and attributes of recreational fishing lakes which might be subject to lake rehabilitation and environmental protection efforts.

The consultants produced an analytical framework to assess the economic implications of specific lake reclamation projects.

B. Costs of Abatement and Mitigation

No specific studies of abatement costs have been carried out by the Ministry. The four major firms targeted by the Countdown Acid Rain program (Ontario Hydro, Inco, Falconbridge and Algoma Steel), will be required to submit cost estimates of abatement programs.

C. Strategy Development and Evaluation Tools

No specific investigations were commissioned in this area during the 1986/87 fiscal year. It is worthy of note, however, that the Ontario Environmental Protection Act was amended during this period. The amendment, Bill 112, contained three provisions.

First, maximum fines for a variety of environmental offences were increased. Second, the duties and responsibilities of MOE officials and the liability of company officials were clarified. Finally, the amendment includes Part X-A, which gives Ministry officials the authority to require a person to whom a ministerial order or approval is issued to provide or deposit financial assurance for:

- the performance of any action specified,
- the provision of alternate water supplies to replace contaminated source,
- measures to prevent adverse effects upon and following the closing of any works or facilities.

Results of previous studies on economic implementation policies commissioned under the auspices of APIOS were used in the design and development of the financial assurance provision of the amendment. These investigations provided evaluations of different economic incentive policies which assisted in focusing Ministry recommendations on the financial assurance policy instrument.

TASK #6 - LEGAL INITIATIVES

A. Provincial Initiatives

Since 1980, Ontario has believed that there was sufficient evidence to implement SO₂ controls immediately while research continues to evaluate the benefits of these controls. As a result, Ontario was the first jurisdiction in North America to mandate emission controls based solely on the effects of long range transport of air pollutants, as distinct from local ambient air quality standards. Ontario Hydro and Inco were the targets of these controls.

In the absence of an acid rain agreement with the United States, the eastern Canadian provinces and the federal government decided in March 1984, to take unilateral action and reduce their sulphur dioxide emissions to a ceiling of 2.3 million tonnes by 1994, a 50% reduction from the 1980 base case year. On February 5, 1985, they agreed to the series of steps to achieve the first 1.9 million tonnes of this reduction and committed to determining the allocation of any further reductions in sufficient time to achieve the 1994 objective.

In December, 1985, Ontario announced its Countdown Acid Rain program and put into place the regulations which required substantial further reductions of the emissions which contribute to acid rain. Almost 80% of all Ontario-produced SO₂ emissions come from four sources; Inco, Ontario Hydro, Algoma Steel (Wawa) and Falconbridge. The regulations require a series of staged reductions to allow time to acquire and install new pollution abatement measures or new, less polluting technology to meet the new limits. The new limits require reductions from a permitted Ontario 1980 base case of 2,194 kilotonnes to less than 885 kilotonnes by 1994. Further information on Ontario's Acid Gas Control Program 1986-1994, is provided in the report entitled Countdown Acid Rain.

The new regulations require that the companies submit semi annual reports to the Ontario government to outline compliance and progress towards the 1994 target. The first two reports have been submitted by the companies and the government is confident that the companies are complying with the legal requirements both in meeting the emission limits and reporting on abatement development.

Countdown Acid Rain will do more than just help Ontario's environment start back to normalcy; it will also reduce acid rain in Quebec and the northeastern United States.

B. International Initiatives

Under the Memorandum of Intent signed in 1980, Canada and the United States agreed to enforce existing laws and regulations in a way which is responsive to the problems of

transboundary air pollution. However, since 1981, the United States Environmental Protection Agency has proposed approving revisions in State Implementation Plans (S.I.P.'s) under Section 110 of the U.S. Clean Air Act which would lead to increases in allowable sulphur dioxide emissions from coal-fired power plants. Therefore, Ontario has undertaken to participate in those U.S. proceedings which could affect, as a result of long range transport, the province's environmental quality. Ontario's efforts have been directed at encouraging the U.S. EPA Administrator and state governments to disapprove any S.I.P. revisions which would result in any increase in permissible emissions of SO₂ in the U.S.

In June 1981, Ontario appeared at the U.S. EPA Section 126 Hearings held in Washington, D.C. in support of the States of New York, Pennsylvania and Maine in their petition concerning Interstate Pollution (Section 126 Clean Air Act). This Section provides for the intervention of the Administrator of the U.S. EPA in instances when interstate air pollution can be shown to be preventing the attainment of national ambient air quality standards or interfering with those prevention of significant deterioration or visibility measures which the Act requires to be included as a part of a state implementation plan. New York and Pennsylvania maintained that SO₂ and particulate sources in the midwest (Ohio, West Virginia, Illinois, Indiana, Michigan, Ohio, Tennessee and Kentucky) were in fact preventing attainment. Maine subsequently consolidated a similar petition with New York and Pennsylvania.

In March 1984, the States of New York, Maine, Vermont, Rhode Island, Connecticut and Massachusetts, together with several environmental groups and United States citizens filed a legal suit against the U.S. EPA that:

- i) the Administrator has violated his mandatory duty under Section 126 to issue a final decision on the petitions regarding interstate air pollution by the deadline (within sixty days) specified in the statute and
- ii) that the Administrator has violated his mandatory duty to determine which states are contributing to air pollution which endangers the public health and welfare of Canada and to give notice to the Governors of such States to revise the State Implementation Plans in order to prevent or eliminate harm.

In December 1984, the U.S. EPA Administrator denied the Section 126 petitions having determined that while pollution does cross state lines into petitioning states, the petitioning states did not adequately support their claims of injury. This decision was appealed to the U.S. Circuit Court of Appeals.

In July 1985, the U.S. federal judge Norma Holloway Johnson ordered the U.S. Environmental Protection Agency to set in motion the necessary processes to reduce acid rain emissions in states where emissions originate. The EPA appealed, saying the court-imposed deadline was "inadequate". The judge decided, on September 24, 1985, to uphold her decision on a nine-month delay, requiring EPA to set in motion steps leading to a reduction in emissions causing acid rain. The same day, EPA appealed the court judgement, questioning the role of the courts and the adequacy of programs directed by judicial order in the acid rain issue. Ontario obtained party status and filed a brief.

In May 1986, U.S. District Court heard arguments from both sides and reserved judgement. In September 1986, the U.S. Court of Appeals for the District of Columbia Circuit rendered its decision to reverse and remand the order to District Court with instructions to dismiss. Ontario jointly petitioned, with the State of Maine, for a re-hearing of the case and was turned down within two weeks.

In February 1987, Ontario and New York filed independent petitions to the U.S. Supreme Court to review the entire case, using writ of certiorari.

In June 1987, the Supreme Court rejected the appeal and let stand an Appeal Court (September 1986) ruling that dismissed the suit.

TASK #7 - PUBLIC RELATIONS INITIATIVES

Muskoka '85 Conference

The Coordination Office and APIOS staff from various program areas were involved in the planning and staging of the International Symposium on Acidic Precipitation which was held in Muskoka in September 1985. Over 700 scientists and environmentalists, representing 20 countries, attended and took part in the program of symposia and poster sessions. Some 500 papers were presented. Proceedings of the conference were published in a three volume edition of "Water, Air and Soil Pollution" in the Spring of 1987.

Countdown Acid Rain

Ontario's new Countdown Acid Rain program was introduced by Environment Minister Jim Bradley in a statement to the provincial legislature in December, 1985.

A press conference followed, with two-way video link-ups with news conferences simultaneously held in Washington, Ottawa, Sudbury, Sault Ste. Marie and Thunder Bay. It was the first time Ontario's teleconferencing system was used extensively for a major event.

An information booklet outlining Ontario's acid gas control program was prepared and has been widely distributed. The first and second semi annual progress reports required of the four major SO₂ emitters by the new Regulations, outlining progress towards achieving the 1994 targets, are summarized and reviewed by the Ontario government and distributed to the public.

Public Awareness Activities

An APIOS Communications Work Group has been reactivated with the objective of preparing an effective public relations strategy to increase awareness among Ontario and American citizens.

A number of initiatives directly aimed at increasing awareness in the U.S. were undertaken with the goal of stimulating Americans to pressure their government for acid gas controls. Initiatives undertaken included the following:

- To increase awareness of the aquatic damage caused by acid rain a fact sheet was prepared outlining the "history" of a lake as it acidifies.
- A poster was prepared picturing seven species of fish with the message: GONE FISHING - FISH GOING? LET'S STOP ACID RAIN.

- The Minister and technical staff participated in the New York Sportsmen's Show. A booth was set up outlining acid rain damages and Ontario's control program. The booth was very popular with those attending the show. Those present were very supportive and many valuable contacts were made.
- An acid rain tour for journalists from the U.S. was initiated by Environment Canada and the Department of External Affairs. A briefing in Toronto by senior MOE officials was followed by tours of Inco and Falconbridge in Sudbury. The journalists also met with concerned Muskoka residents. The journalists flew to Quebec on the second day and met with the Quebec Maple Producers Association.
- In cooperation with Environment Canada, Ontario hosted a tour for the U.S. NAPAP Director of Research and his senior scientific staff. Ontario Hydro's Nanticoke and Bruce generating stations were viewed from the air. Inco and Falconbridge facilities in Sudbury were toured. The party also visited the Dorset Research Centre and were briefed on work underway on the aquatic, terrestrial and biogeochemical effects of acid rain, as well as the air monitoring components.
- A tear off card was provided with the application form for all non resident angling licenses. This card may be returned requesting information on acid rain. A package of appropriate information was assembled and is being mailed out upon receipt of the completed card. In this way the user group, fishermen, is targeted and informed of potential losses in the resource due to acid deposition.

Efforts to increase awareness and maintain interest in Ontario included an Open House at Dorset, participation at the Toronto Sportsmen's Show and Federation of Ontario Cottager's Association meetings. Communications Branch and APIOS staff also manned the acid rain display at the North American Wildlife Conference in Quebec City.

Presentations were made at the request of associations and special interest groups. Extensive distribution of materials continued to students, teachers and the public.

SUMMARY

At the end of Fiscal 1986/87 the APIOS program has contributed to the understanding of the acid rain problem in Ontario and the following conclusions/milestones were reached:

- The Countdown Acid Rain program, announced in December 1985, has been demonstrated to be an effective mechanism for decreasing emissions of SO₂ in Ontario. Semi annual progress reports are being submitted by the four major companies outlining compliance activities and abatement technology being investigated.
- The eulerian long range transport model (ADOM) was installed at University of Toronto's CRAY XMP computer and will be used to investigate the impact of emission reductions in Canada and the United States.
- Initial planning, site selection and equipment acquisition took place for the international evaluation and field verification of the eulerian model.
- Investigations were conducted into the effectiveness of hydrocarbon versus NO_x control in southern Ontario as a means to control O₃. Although work is continuing, preliminary results indicate that control of hydrocarbons may be more effective.
- Programs were developed to merge MDAS meteorological data and data from Ontario air quality monitoring network so that both types of data may be analyzed together.
- Mercury concentrations in acidified lakes are typically elevated. Data show that mercury concentrations are low in spring but may reach high levels in summer or fall. Concentrations in brown water streams are about 10 fold higher than in clear streams.
- A comparison of data from Daphnia surveys indicates that biomass is reduced after relatively modest pH depression. Acidification may be accompanied by replacement of acid sensitive species by acid tolerant species. Overall, zooplankton biomass increases with increases in pH in Dorset area lakes.
- A comparison of survey data indicates that many mayfly and stonefly taxa that are intolerant of low pH were present 50 years ago and are not present now. By way of contrast, preliminary data indicate that blackfly biomass has increased.

- Studies investigating the relative roles of hydrogen ion and inorganic aluminum determined that hydrogen ion is the master variable driving the response of fish to acidification.
- Field and lab data were used to determine the smallmouth bass and walleye sensitivity to low pH. Estimates were made of the number of lakes where fish were either lost (walleye 12, smallmouth bass 57) or endangered (walleye 80, smallmouth bass 296).
- Aurora trout have been successfully reintroduced into one of the native lakes. Growth and survival will be monitored to determine whether these trout will reproduce.
- Studies determined that the embryo of the leopard frog is the stage most sensitive to low pH.
- Investigation of cadmium levels in goldeneye feathers found concentrations that were higher by a factor of 10 than other published data.
- Studies of cadmium in moose demonstrated levels comparable to those found in Quebec and consistently higher than those in Manitoba, Maine and Scandinavia.
- Preliminary work correlating cadmium in deer pellets from geophysically sensitive and non sensitive areas indicates that cadmium levels are higher in deer from sensitive areas.
- Results of a joint OMAF/MOE questionnaire distributed to 600 Ontario Maple Syrup Producers Association indicated that one third of the woodlots were experiencing decline.
- Data from 100 hardwood plots across Ontario indicate that decline indices follow climatic (temperature) isoclines, increasing as one moves northward, with the exception of the southernmost part of the province.
- The financial value model developed in 1980/81 was reviewed in terms of improving and updating the forestry, agriculture and materials corrosion components.
- A questionnaire survey of 5,200 cottagers on 204 lakes determined that filamentous algae are present in 47% of central Ontario lakes and odour producing algae are present in 6% of the lakes.
- A number of public relations activities were initiated to increase awareness among U.S. citizens of the damage being caused to both our environments in an attempt to obtain abatement legislation. These

initiatives include participation at the New York Sportsmen's Show, NAPAP Tour of Ontario research projects, journalists tours in Ontario and Quebec and the provision of acid rain information to non resident anglers fishing in Ontario.

APPENDIX I

INTERNATIONAL LRTAP PROJECTS - MOE CO-FUNDING

<u>Project Title</u>	<u>Funding Agencies</u>	<u>Purpose</u>
Acid Deposition and Oxidants Model (ADOM)	Environment Ontario Atmospheric Environment Service Umweltbundesamt (West Germany) Environment Quebec State of Minnesota State of New York Electric Power Research Institute	To improve predictions of source/receptor relationships, through the use of eulerian concepts.
Bilateral Hardwood Decline Study	Environment Ontario Ministry of Natural Resources Environment Canada Department of Natural Resources - New Brunswick Ministry of Energy and Resources - Quebec Northeast Forest Cooperative	A study of the etiology of sugar maple decline across northeastern North America using a common methodology.
Dry Deposition Intercomparison Measurements	Environment Ontario Atmospheric Environment Service Illinois State Water Survey Nation Aeronautical Establishment U.S. Department of the Interior National Oceanic and Atmospheric Administration Environmental Protection Agency Argonne National Laboratory Oregon State University	To improve quality control and comparability of Canada/U.S. results.

<u>Project Title</u>	<u>Funding Agencies</u>	<u>Purpose</u>
Eulerian Model Field Verification	Environment Ontario Environment Canada U.S. E.P.A. Electric Power Research Institute	A study design has been prepared for the field verification of the eulerian model.
Rain Acidity Interlaboratory Study of Damage to Agricultural Crops	Environment Ontario Boyce Thompson Institute Argonne International Laboratory Corvallis Environmental Research Laboratory Oakridge National Laboratory Brookhaven National Laboratory	To measure the effects of different pH's on crops and to standardize techniques and procedures. Study has been completed. A similar study is being developed for exclusion canopy work.
Reversing Acidification in Norway - NIVA	Environment Ontario Norway Sweden Environment Canada United Kingdom	To test hypotheses on watershed sensitivity and to measure watershed response to reductions and increases in acid loadings. This issue has been recently raised by the U.S. E.P.A. as an impediment to designing a control program.
Unified Acid Deposition Data Base for Eastern North America	Environment Ontario Environment Canada National Atmospheric Deposition Program, U.S. Geological Survey Battelle Pacific Northwest Laboratory, U.S.	The unified data base should be useful for mathematical model evaluation and historical trend analysis

INTERNATIONAL LRTAP PROJECTS - MOE PARTICIPATION

<u>Project Title</u>	<u>Participating Agencies</u>	<u>Purpose</u>
Aluminum Biogeochemistry in Forested Watersheds	Electric Power Research Institute Environment Ontario Environment Canada United States West Germany Norway Sweden United Kingdom	To identify and quantify the release, transport and toxicity of aqueous aluminum in the natural environment. Aluminum is toxic to both fish and trees.
BACG (Bilateral Advisory Consultative Group)	Environment Ontario Ministry of Energy Ministry of External Affairs Environment Quebec Environment Canada Office of the President Department of State, U.S. Department of Energy, U.S. U.S. EPA National Acidic Precipitation Assessment Program	To respond to or implement recommendations of the Special Envoys' Report
CAPTEX Data Analysis and Model Comparisons	Environment Ontario Environment Canada National Oceanic and Atmospheric Administration, U.S. Department of Energy, U.S.	A workshop on the Cross Apalachian Tracer Experiment (CAPTEX) was held November, 1985 to compare model predictions with ground-level tracer concentrations.
Free Aluminum in Surface Waters	Environment Ontario University of Maine	Agreement for interchange of samples for analysis to determine comparability of the methodologies.

<u>Project Title</u>	<u>Participating Agencies</u>	<u>Purpose</u>
Fisheries Loss Assessment Program	NAPAP Environment Ontario Ontario Ministry of Natural Resources EPRI Environment Canada	To assist NAPAP in the design of a program to assess fisheries loss in the U.S. related to acidic deposition.
Human Health Effects Related to Aquatic Effects of Acid Deposition	EPA Environment Ontario Various State Health Agencies	MOE has been invited to sit on a Committee of experts to determine the exact nature and extent of these human health effects.
Informal Calibrated Watershed Modelling Group	Environment Ontario Environment Canada United States Norway Sweden	To compare results and ideas on watershed studies. The work defines effects of acid rain and develops target loadings to prevent damage.
Interlaboratory Quality Assurance	Government and private laboratories in Canada and the U.S. (over 50 labs involved, including MOE)	To ensure the validity and compatibility of all data collected under LRT programs in North America.
Lake Acidification Mitigation Program	EPRI Clarkson College Environment Ontario	MOE has been requested to provide advice and information concerning lake liming projects.
National Acidic Precipitation Assessment Program Review	Environment Ontario Environment Canada Fisheries and Oceans Canadian Forestry Service Government and Private Laboratories in U.S.	Review of NAPAP interim assessment document findings.

<u>Project Title</u>	<u>Participating Agencies</u>	<u>Purpose</u>
National Surface Water Survey	EPA Environment Ontario Environment Canada	To characterize current water chemistry of lakes and streams in five U.S. Regions. MOE has been requested to assist in the development of the survey design.
Ontario/Germany Memorandum of Understanding	Ontario Federal Republic of Germany	To exchange information, scientists and modelling results to ensure that similar methodologies are used so that final results may be compared.
Ontario/Michigan Memorandum of Understanding	Ontario Michigan	To exchange information and perform joint studies to achieve and maintain a quality of environment to protect human health and the ecosystem where activities of one jurisdiction may affect the environment of the other.
Ontario/Minnesota Memorandum of Understanding	Ontario Minnesota	To exchange information on acid rain; to cooperate on specific projects (atmospheric modelling, RAIN - NIVA, aquatic effects in a medium deposition area).
Ontario/New York Memorandum of Understanding	Ontario New York	To exchange information on acid rain to improve understanding of acidification of the environment and establish coordinated courses of action in order to encourage abatement measures on an international basis.

Project Title

Ontario/NADP Intercomparison
Study - Ely, Minnesota

Participating Agencies

Ontario
National Atmospheric Deposition
Program

Purpose

To improve comparability of
data.

APPENDIX II

A.P.I.O.S. RELATED TECHNICAL REPORTS AND SUBMISSIONS

1987

- An Assessment of Source Contributions to the Ozone Concentrations in Southern Ontario 1979 - 1985.
Yap, D., Ning, D.T. and Dong, W. Ontario Ministry of the Environment Report No. ARB-101-87-AQM.
- Annual Statistics of Concentration and Deposition - Cumulative Precipitation Sites in Industrial/Urban Areas in Ontario. January 4, 1983 - January 15, 1985.
APIOS #001/87.
- Annual Statistics of Concentration and Deposition - Cumulative Precipitation Monitoring Network 1985.
APIOS #002/87.
- Technical and Operating Manual. APIOS Deposition Program.
APIOS #003/87.

1986

- A Historical Perspective of Sugar Maple Decline Within Ontario and Outside of Ontario, December 1986.
McIlveen, W.D., Rutherford, S.T. and S.N. Linzon.
APIOS #010/86 ARB-141-86-Phyto.
- A Unified Wet Deposition Data Base for Eastern North America: Addendum with Results for Sulfates and Nitrates (1980 - 1983). Prepared by the Unified Deposition Data Base Committee (M. Lusic, Coordinator), 1986.
- An Evaluation of Sampler Types and Sampling Periods for Measurements of Wet and Dry Deposition. Chan, W.H., Tang, A.J.S., Bardswick, W.S., Orr, D. and M.A. Lusic.
Report ART-098-85-AQM, 1986. APIOS 19-85.
- Abundance of Chaoborus Larvae in Chub Lake: Sampling Methods and 1982 data. Lasenby, D.C., Morris, K. and N.D. Yan. Ont. Min. Env. Data Report DR 86/3.
- Assessment of Aquatic and Terrestrial Acidic Precipitation Sensitivities for Ontario. D.W. Cowell. Joint Federal/Provincial. APIOS #009/86, ARB-220-86-Phyto.
- Bryophyte Flora of Acid-Sensitive Lakes in South-Central Ontario: Description and Mechanisms of Sphagnum Invasion. Manville, G.C. and N.D. Yan. Ont. Min. Env. Tech. Rep. (in press).

1986 (continued)

Precipitation and Air Concentration and Wet and Dry Deposition Field of Pollutants in Ontario, 1983. Acidic Precipitation in Ontario Study. ARB-008-86-AQM. APIOS-001-86.

Procedures Manual - Terrestrial Effects. Acidic Precipitation in Ontario Study (APIOS). ARB-93-86-Phyto. February 1986.

Studies of Lakes and Watersheds in Muskoka-Haliburton, Ontario: Methodology (1976-1985). Locke, B.A. and L.D. Scott. Ont. Min. Env. Data Report DR 86/4.

Summary: Some Results from the APIOS Atmospheric Deposition Monitoring Program (1981 - 1984). Tang, A.J.S., Ahmed, A. and M.A. Lusi. ARB-110-86, APIOS-011-86.

User Manual for the Lab Information System (LIS), Dorset Research Centre. Nicolls, A., Locke, B.A. and S.A. McCormick. Ont. Min. Env. Data Report DR 86/2.

Inventoried Air Pollution Emissions of Sulphur Dioxides, Nitrogen Oxides and Volatile Organic Compounds for the Province of Ontario (1980 - 1983). Wong, S.K.S., Yap, D. and Huynh, Q.I. Ontario Ministry of the Environment Report No. ARB-187-86-AQM.

1985

A Unified Wet Deposition Data Base for Eastern North America: Data Screening, Calculation Procedures, and Results for Sulphates and Nitrates (1980). Prepared by the Unified Deposition Database Committee (M. Lusi, Coordinator), 1985.

Air Concentration and Dry Deposition Fields of Pollutants in Ontario, 1982. APIOS Report No. 001/85.

An Assessment of the Performance of the Daily Precipitation and Air Sampling Networks, July 1980 - December 1981. Acidic Precipitation in Ontario Study. Report ARB-100-85-AQM.

Annual Statistics of Concentration - Cumulative Ambient Air Monitoring Network, 1983. Acidic Precipitation in Ontario Study. Report ARB-089-85-AQM.

Annual Statistics of Concentration - Cumulative Ambient Air Monitoring Network, 1984. Acidic Precipitation in Ontario Study. Report ARB-237-85-AQM.

1985 (continued)

- Annual Statistics of Concentration and Deposition -
Cumulative Precipitation Monitoring Network, 1984.
Acidic Precipitation in Ontario Study. Report
ARB-235-85-AQM.
- Annual Statistics of Concentration and Deposition -
Cumulative Precipitation Sites in Industrial/Urban Areas
in Ontario, 1981 and 1982. APIOS Report No. 005/85.
- Annual Statistics of Concentration and Deposition -
Cumulative Precipitation Monitoring Network, 1983.
Acidic Precipitation in Ontario Study. Report
ARB-087-85-AQM.
- Annual Statistics of Concentration and Deposition - Daily
Precipitation and Air Monitoring Networks. Acidic
Precipitation in Ontario Study, 1983. Report
ARB-109-85-AQM.
- Annual Statistics of Concentration and Deposition - Daily
Precipitation and Air Monitoring Network, 1984. Acidic
Precipitation in Ontario Study. Report ARB-236-85-AQM.
- Cumulative Ambient Air Concentration Listings. January 4,
1983 - January 3, 1984. Acidic Precipitation in Ontario
Study. Report ARB-088-85-AQM.
- Cumulative (28 Day) Precipitation Chemistry Listings of
Sites in Industrial/Urban Areas in Ontario, September
1980 - January 1983. APIOS Report No. 003/85.
- Cumulative (28 Day) Precipitation Chemistry Listings,
January 4, 1983 - January 4, 1984. Acidic Precipitation
in Ontario Study. Report ARB-063-85-AQM.
- Daily Ambient Air Concentration Listings. Acidic
Precipitation in Ontario Study. Report ARB-108-85-AQM.
- The Morphometry and Geology of Plastic and Heney Lakes and
Their Catchments. Girard, R., Reid, R.A. and
W.R. Snyder. Ont. Min. Env. Data Report DR 85/1.
- 1983 Daily Precipitation Chemistry Listings. APIOS Report
No. 004/85.
- Ontario Soil Baseline Survey Analytical Data 1980/81.
APIOS Report No. 002/85. Three Volumes.
- Quality Assurance Management Programme for the Limnology
Unit, Dorset Research Centre. Locke, B.S. Ont. Min.
Env. Data Report DR 85/4.
- Quality Assurance Manual. Deposition Monitoring Networks.
Acidic Precipitation in Ontario Study. APIOS Report
No. 006/85. February 1985.

1985 (continued)

The Sarnia Oxidants Study (June 27 - July 18, 1984):
Analysis of the Air Quality and Meteorological Data.
Lusis, M.A., Sahota, H. and D. Yap. Report
ARB-124-85-AQM.

The Sarnia Oxidants Study (June 27 - July 18, 1984):
Report on the Airborne Measurements. Sahota, H.,
Kiely, P. and M. Lusis. Report ARB-019-85-ARSP.

Sugar Maple Decline in Ontario. McLaughlin, D.L.,
Linzon, S.N., Dimma, D.E. and W.D. McIlveen. Report
ARB-144-85-Phyto. APIOS 026/85.

Temperature and Oxygen Data for the Muskoka-Haliburton
Study Lakes (1983-1984). Reid, R.A. and R. Girard.
Ont. Min. Env. Data Report DR 85/2.

Temperature, Oxygen, pH and Dissolved Inorganic Carbon Data
Summary for Eight Lakes in the Muskoka-Haliburton Study
Area (1982-1984). Girard, R. and R.A. Reid. Ont. Min.
Env. Data Report DR 85/3.

Water Quality Changes in Sudbury area lakes, 1974-76 to
1982-83. Ont. Min. Env. Tech. Rep. APIOS 007/85.
29 p.

1984

An Analysis of the Effects of the Sudbury Emissions Sources
on Wet and Dry Deposition in Ontario. Tang, A.J.S. and
W.H. Chan. APIOS Report No. 011/84.

An Assessment of the Performance of the Cumulative
Precipitation Monitoring Network - June, 1980 -
December, 1981. Acidic Precipitation in Ontario Study.
W.S. Bardswick. Report ARB-143-84-ARSP.

Annual Program Report - Fiscal Year 1982/1983. APIOS
Report No. 001/84.

Annual Program Report - Fiscal Year 1983/1984. APIOS
Report No. 010/84.

Annual Statistics of Concentration, Cumulative Ambient Air
Monitoring Network, 1982. APIOS Report No. 015/84.

Annual Statistics of Concentration and Deposition -
Cumulative Precipitation Monitoring Network, 1982.
APIOS Report No. 008/84.

Annual Statistics of Concentration and Deposition - Daily
Precipitation and Air Monitoring Network, 1982. APIOS
Report No. 009/84.

1984 (continued)

Cumulative Ambient Air Concentration Listings August 31, 1981 - January 4, 1983. APIOS Report No. 013/84.

Cumulative (28 Day) Precipitation Chemistry Listings - January 5, 1982 - January 4, 1983. APIOS Report No. 003/84.

The Economics of Acid Precipitation: A Review of Socio-Economic Methods to Assess Acid Deposition Effects. APIOS Report No. 006/84.

Emission Inventory of Ontario and Eastern North America during 1980-1983 with Emphasis on the Sudbury Shut-down Period. D. Yap. APIOS Report No. 016/84.

Examination of Monthly Wet Sulphate Deposition by a Lagrangian Model and its Application to Study the Effects of Source Control on Receptors. Ellenton, G. and P.K. Misra. APIOS Report No. 018/84.

Macrophyte Data from 46 Southern Ontario Soft Water Lakes of Varying pH. Hitchin, G.G., Wile, I., Miller, G.E. and N.D. Yan. Ont. Min. Env. Data Report DR 84/2.

Meteorological Studies to Quantify the Effects of Sudbury Emissions on Precipitation Quality and Air Quality During 1980-1983 with Emphasis on the Shut-down period. Kurtz, J. and D. Yap. APIOS Report No. 17/84.

1982 Daily Ambient Air Concentration Listings. APIOS Report No. 004/84.

1982 Daily Precipitation Chemistry Listings. APIOS Report No. 002/84.

An Overview of the Cumulative Wet/Dry Deposition Network. APIOS Report No. 007/84.

An Overview: The Cumulative Wet/Dry Deposition Network. Chan, W.H., Orr, D.B. and R.J. Vet. APIOS Report No. 005/84.

Physical and Chemical Data Summary for Twelve Selected Lakes in the Muskoka-Haliburton Area (1981-1983). Reid, R.A., Locke, B.A., Girard, G.E. and A.C. Nicolls. Ont. Min. Env. Data Report DR 84/1.

Precipitation Concentration and Wet Deposition Fields of Pollutants in Ontario, 1982. APIOS Report No. 012/84.

Quality Assurance Plan - APIOS Deposition Monitoring Program.

Summary: Source Apportionment Analysis of Air and Precipitation Data to Determine Contribution of the Sudbury Smelters to Atmospheric Deposition in Ontario. Lusi, M.A. APIOS Report No. 019/84.

1983

Acid Sensitivity Survey of Lakes in Ontario. APIOS Report No. 001/83.

Acidic Precipitation in Ontario Study - Technical and Operating Manual, APIOS Deposition Monitoring Program. Bardswick, W.S. April 1983.

Annual Statistics of Concentration and Deposition - Cumulative Precipitation Monitoring Network, 1981. Kirk, R.W. August 1983. APIOS Report No. 008/83.

Annual Statistics of Concentration and Deposition - Cumulative Precipitation Monitoring Network, 1981. Kirk, R.W. September 1983.

APIOS Daily Precipitation Chemistry Listings, July 15, 1980 - December 31, 1981. Revised Edition January 1983.

APIOS Monthly/28 Day Cumulative Precipitation Chemistry Listings, June 1980 - December 1981. March 1983.

Area Source Emission Inventory for Nitrogen Oxides in Ontario by Ontario Research Foundation for MOE. Final Report (Proposal No. p-4261/G). September 1983.

Crustacean Zooplankton Communities of the Muskoka-Haliburton Study Lakes: Methods and 1976-1979 Data. Hitchin, G.G. and N.D. Yan. Ont. Min. Env. Data Report DR 83/9.

Daily Ambient Air Concentration Listings, July 25, 1980 - December 31, 1981. May 1983.

Depth and Volume of Strata in the Muskoka-Haliburton Study Lakes (1976-1982). Girard, R., Locke, B.A. and R.A. Reid. Ont. Min. Env. Data Report DR 83/10.

Geology and Geochemistry of the Muskoka-Haliburton Study Area. Jeffries, D.S. and W.R. Snyder. Ont. Min. Env. Data Report DR 83/2.

Hydrological Data for Lakes and Watersheds in the Muskoka-Haliburton Study Area (1976-1980). Scheider, W.A., Cox, C.M. and L.D. Scott. Ont. Min. Env. Data Report DR 83/6.

The Macrophyte Flora of 46 Acidified and Acid Sensitive Soft Water Lakes in Ontario. Wile, I. and G. Miller. Ont. Min. Env. Tech. Rep.

Meteorological Analysis of Precipitation Event Sampling Data (July 1980 - December 1981). Kurtz, J. June 1983.

1983 (continued)

- Morphometry of the Muskoka-Haliburton Study Lakes.
Nicholls, A., Reid, R. and R. Girard. Ont. Min. Env.
Data Report DR 83/8.
- 1981 Summary Statistics of Observed Concentration and
Deposition: Daily Precipitation Monitoring Network.
Kirk, R.W. and W.H. Chan. June 1983.
- Oxygen Profiles on the Muskoka-Haliburton Study Lakes
(1976-1982). Reid, R.A., Girard R. and B.A. Locke.
Ont. Min. Env. Data Report DR 83/5.
- A Performance and Systems Audit of the Acidic Precipitation
in Ontario Study Monitoring Networks, Volume 1 and
Volume 2 (Appendices). Submitted by Concord Scientific
Corporation. ARB-69-83-ARSP. 1983.
- Phytoplankton of Lakes in the Muskoka-Haliburton Area.
Nakomoto, L., Heintsch L. and A. Nicholls. Ont. Min.
Env. Data Report DR 83/8.
- Precipitation Concentration and Wet Deposition Fields of
Pollutants in Ontario, September 1980 to December 1981.
Chan, W.H., Tang, A.J.S. and M.A. Lusi. June 1983.
- A Preliminary Study for the Compilation of a VOC Emission
Inventory for the Province of Ontario by Concord
Scientific Corporation for MOE. Final Report CSC
110.260. June 1983.
- Procedures Manual - Terrestrial Effects. Griffin H.D.
(Ed.). APIOS Report No. 007/83.
- The Province of Ontario. Presentation to the Michigan Air
Pollution Control Commission in Opposition to the
Consumers Power Company Request to Delay Bringing its
J.H. Campbell and B.C. Cobb Power Plants into Compliance
with the Michigan "One Percent or Equivalent Sulphur in
Fuel" Rule. Grand Haven, Michigan. November 28, 1983.
- Sediment Chemistry of Lakes in the Muskoka-Haliburton Study
Area. Smith, P.J. Ont. Min. Env. Data Report DR 83/7.
- Studies of Lakes and Streams: Pukaskwa National Park.
Sutton, J., Maki, L., Deacon, K.J. and G.W. Ozburn.
API 003/83.
- Studies of Lakes and Watersheds in Muskoka-Haliburton,
Ontario: Methodology (1976-1982). Scheider, W.A.,
Reid, R.A., Locke, B. and L.D. Scott. Ont. Min. Env.
Data Report DR 83/1.
- Temperature Profiles on the Muskoka-Haliburton Study Lakes
(1976-1982). Reid, R.A., Locke, B. and R. Girard. Ont.
Min. Env. Data Report DR 83/4.

1983 (continued)

Total Phosphorus and Major Ion Mass Balances for Lakes in the Muskoka-Haliburton Study Area (1976-1980).
Dillon, P.J. and W.A. Scheider. Ont. Min. Env. Data Report DR 83/11.

Water Quality-Crustacean Plankton Relationships in Northeastern Ontario Lakes. Keller, W. and J.R. Pitblado. API 002/83.

1982

Acid Sensitivity Survey of Lakes in Ontario. APIOS 003/82. Summer 1982.

The Case Against the Rain: A Report on Acidic Precipitation and Ontario Programs for Remedial Action. Reprint with Supplementary Insert - Summer 1982.

Daily Precipitation Chemistry Listings and Statistical Summaries July 15, 1980 - December 31, 1981. APIOS 001/82.

The Economics of Acid Precipitation: Ontario's Socio-economic Research Program. API 007/82. December 1982.

Experimental Neutralization of a Small, Seasonally Acidic Stream Using Crushed Limestone. API 004/82. Summer 1982.

Lagrangian Model of the Long Range Transport of Sulphur Oxides. API 008/82. Fall 1982.

Monitoring of Lake Superior Tributaries, 1980-1981. API 009/82. Fall 1982.

An Overview: The Cumulative Wet/Dry Deposition Network. December 1982.

An Overview: The Event Wet/Dry Deposition Network. API 002/82. Summer 1982.

The Province of Ontario. Presentation to the Michigan Air Pollution Control Commission in Opposition to the Detroit Edison Request to Delay Bringing its Monroe Power Plant into Compliance with the State of Michigan "1% or Equivalent Sulphur in Fuel" Rule. Monroe, Michigan. June 30, 1982.

Report of the Ontario/Canada Task Force for the Development and Evaluation of Air Pollution Abatement Options for Inco Limited and Falconbridge Nickel Mines, Limited in the Regional Municipality of Sudbury, Ontario. December 21, 1982.

1982 (continued)

- Standard Methods for National Wet-only Precipitation Sampling and Chemistry Analysis. McQuaker, N.R., Kluckner, P.D., Torneby, J.E., Sorba, S.E., Chan, W.H. and M.E. Still., A Joint Report with the Federal and Other Provincial Governments. 1982.
- A Synoptic Survey of the Acidity of Ground Waters in the Muskoka-Haliburton Area of Ontario, 1980. API 006/82. Fall 1982.
- A Synoptic Survey of the Acidity of Ground Waters in the Sudbury Area of Ontario, 1981. API 005/82. Fall 1982.

1981

- Acid Sensitivity Survey of Lakes in Ontario. API 002/81. March 1981.
- An Annotated Bibliography: Terrestrial Effects of Acidic Precipitation. APIOS 003/81. July 1981.
- Chemical, Microbiological and Physical Interactions of Acidic Precipitation Within a Lake and its Drainage Basin. Flett, R.J. API 004/81. July 1981.
- An Intercomparison Study of Three Precipitation Sampling Networks in Ontario - APIOS, CANSAP and GLPN. Vet, R.J., Chan, W.H. and M.A. Lusi. Report No. ARB-002-91-ARSP. September 1981.
- Lakewide Odours in Ontario and New Hampshire Caused by Chrysochromulina breviturrita Nich. (Pymnesiophyceae). API 001/81. 1981.
- Ontario Ministry of the Environment. Studies of Lakes and Watersheds Near Sudbury, Ontario: Final Limnology Report of the Sudbury Environmental Study: Volume I.
- Ontario Ministry of the Environment. Studies of Lakes and Watersheds Near Sudbury, Ontario: Final Limnology Report of the Sudbury Environmental Study: Volume II. Appendices.
- The Province of Ontario. Presentation to the Air Pollution Control Board of the State of Indiana in Opposition to the Indiana-Kentucky Electric Generating Station Petition to Operate With an Increase in its Sulphur Dioxide Emissions to 7.52 pounds of SO₂ per Million BTU's of Heat Input. Indianapolis, Indiana. October 7, 1981.
- The Province of Ontario. A Submission to the United States Environmental Protection Agency Hearing on Interstate Pollution Abatement. Washington, D.C. June 19, 1981.

1981 (continued)

The Province of Ontario. A Submission to the United States Environmental Protection Agency on Interstate Pollution Abatement. December 1981. Docket No. A-81-09.

The Province of Ontario. A Submission to the United States Environmental Protection Agency Opposing Relaxation of SO₂ Emission Limits in state Implementation Plans and Urging Enforcement. March 12, 1981. Expanded March 27, 1981.

The Seasonal Dependence of Atmospheric Deposition and Chemical Transformation Rates for Sulphur and Nitrogen Compounds. Lysis, M.A. and L. Shenfeld. Report No. ARB-018-ARSP. 1981.

Simple Nitrogen Oxides Chemistry for Incorporation into Long Range Mathematical Models. Prepared by Concord Scientific Corporation. Report No. ARB-008-81-ARSP. February 1981.

1980

Acidic Precipitation in South-Central Ontario: Analysis of Source Regions Using Air Parcel Trajectories. Kurtz, J. and W. Scheider. MOE Report, May 1980.

Bulk Deposition in the Sudbury and Muskoka-Haliburton Areas of Ontario During the Shutdown of Inco Ltd. in Sudbury. Scheider, W.A., Jeffries, D.S. and P.J. Dillon. May 1980.

The Case Against the Rain: A Report on Acidic Precipitation and Ontario Programs for Remedial Action. October 1980.

Precipitation Sampler Comparative Study. Report Number ARB-007-81-ARSP. May 1980.

1979

Ontario Ministry of the Environment. Determination of the Susceptibility to Acidification of Poorly Buffered Surface Waters. Ont. Min. Env. Tech. Rep., 21 p.

Survival of Rainbow Trout, Salmo gairdneri in Submerged Enclosures in Lakes Treated with Neutralizing Agents Near Sudbury, Ontario. Yan, N.D., Girard, R.E. and C.L. Lafrance. Ont. Min. Env. Tech. Rep. LTS 79-2, 29 p.

1978

Acid Precipitation: A Review. Yan, N.D. Tech. Rep. EE-9. 35 p.

A.P.I.O.S. RELATED PUBLICATIONS/PAPERS

- Bardswick, W.S., Chan, W.H. and D.B. Orr. 1986. A Quality Assurance Program and Quality Assessment of the Acidic Precipitation in Ontario Study (APIOS) Deposition Monitoring Networks. Water, Air and Soil Pollution 30:981-990.
- Barrie, L.A., Lindberg, S.E., Chan, W.H., Ross, H.B., Arimoto, R. and T.M. Church. 1986. On the Concentration of Trace Metals in Precipitation Atmospheric Environment (in press).
- Bisessar, S., Palmer, K.T., Kuja, A.L. and S.N. Linzon. (1984). Influence of Simulated Acidic Rain on Bacterial Speck of Tomato. Journal of Environmental Quality, Vol. 13, pp. 18-22.
- Bloxam, R.M., Misra, P.K. and B.E. Ley. 1986. Variable Washout Ratios in Lagrangian Models, Second APCA Specialty Conference on Meteorology of Acidic Deposition, 1986, p. 72.
- Chan, W.H. 1982. Quality Assurance - Monitoring of Wet Deposition. Presented at the Symposium on Monitoring and Assessment of Airborne Pollutants with Special Emphasis on Long-Range Transport and Deposition of Acidic Materials, National Research Council of Canada, Ottawa, Ontario, August 30 - September 1, 1982.
- Chan, W.H. 1982. Sudbury Environmental Study - Atmospheric Research Program. Report ARB-27-82-ARSP.
- Chan, W.H. and D.H.S. Chung. 1986. Regional Scale Precipitation Scavenging of SO₂, SO₄, NO₃ and HNO₃. Atmospheric Environment 20:1397-1402.
- Chan, W.H. and M.A. Lusi. 1985. Post-Superstack Sudbury Smelter Emissions and Their Fate in the Atmosphere: An Overview of the Sudbury Environmental Study. Water, Air and Soil Pollution 26:43-58.
- Chan, W.H. and M.A. Lusi. 1986. Smelting Operations and Trace Metals in Air and Precipitation in the Sudbury Basin in "Toxic Metals in the Air". Nriagu, J.O. and C.I. Davison, (Eds.), John Wiley and Sons.
- Chan, W.H., Lusi, M.A., Stevens, R.D.S. and R.J. Vet. 1984. A Precipitation Sampler Intercomparison. Water, Air and Soil Pollution 23:1-13.
- Chan, W.H., Orr, D.B. and D.H.S. Chung. 1986. An Evaluation of Artifact SO₄ Formation on Nylon Filters under Field Conditions. Atmospheric Environment 20:2397-2401.

- Chan, W.H., Ro, C.U., Vet, R.J., Tang, A.J.S. and M.A. Lusiš. 1983. Precipitation Scavenging and Dry Deposition of Pollutants from the Inco Nickel Smelter in Sudbury. Proceedings of the 4th International Conference on Precipitation Scavenging, Dry Deposition and Resuspension, G. Slinn, (Ed.), Elsevier Science Publishing Co. Inc., 1983.
- Chan, W.H., Tang, A.J.S., Chung, D.H.S. and M.A. Lusiš. 1982. Concentration and Deposition of Trace Metals in Ontario - 1982. Water, Air and Soil Pollution 29:373-389.
- Chan, W.H., Tang, A.J. and M.A. Lusiš. 1983. Precipitation Concentration and Wet Deposition Fields of Pollutants in Ontario, 1981. Report ARB-61-83-ARSP.
- Chan, W.H., Vet, R.J., Lusiš, M.A. and G.B. Skelton. 1983. Airborne Particulate Size Distribution Measurements in Nickel Smelter Plumes. Atmospheric Environment 17:1173-1181.
- Chan, W.H., Vet, R.J., Lusiš, M.A. and G.B. Skelton. 1982. Size Distribution and Emission Rate Measurements of Particulates in the Inco 381 M Chimney and Iron Ore Recovery Plant Stack Plumes, 1979-80. Report ARB-TDA-62-80.
- Chan, W.H., Vet, R.J., Ro, C.U. and M.A. Lusiš. 1982. Impact of the Inco Nickel Smelter Emissions on Precipitation Quality in the Sudbury Area. Atmospheric Environment 16:801-814.
- Chan, W.H., Vet, R.J., Ro, C.U., Tang, A.J.S. and M.A. Lusiš. 1982. An Analysis of the Impact of Smelter Emissions on Atmospheric Dry Deposition in the Sudbury Area: Sudbury Environmental Study Airborne Particulate Matter Network Results. Report ARB-012-81-ARSP.
- Chan, W.H., Vet, R.J., Ro, C.U., Tang, A.J.S. and M.A. Lusiš. 1982. An Analysis of the Impact of Smelter Emissions on Precipitation Quality and Wet Deposition in the Sudbury Area: Sudbury Environmental Study Event Precipitation Network Results. Report ARB-05-82-ARSP.
- Chan, W.H., Vet, R.J., Ro, C.U., Tang, A.J.S. and M.A. Lusiš. 1984. Impact of Inco Smelter Emissions on Wet and Dry Deposition in the Sudbury Area. Atmospheric Environment 18:1001-1008.
- Chan, W.H., Vet, R.J., Ro, C.U., Tang, A.J.S. and M.A. Lusiš. 1984. Impact of Smelting Activities on Long-Term Precipitation Quality and Wet Deposition Fields in the Sudbury Basin. Atmospheric Environment 18:1175-1188.

- Chan, W.H., Vet, R.J., Ro, C.U., Tang, A.J.S. and M.A. Lusi. 1982. Precipitation Quality and Wet Deposition in the Sudbury Basin: Sudbury Environmental Study Cumulative Precipitation Network Results. Report ARB-04-82-ARSP.
- Chan, W.H., Vet, R.J., Skelton, G.B. and M.A. Lusi. 1982. Size Distribution and Emission Rate Measurements of Particulates in the 93 M Falconbridge Smelter Stack Plume, 1979. Report ARB-TDA-57-80.
- Clark, K.L. and R.J. Hall. 1985. Effects of Elevated Hydrogen Ion and Aluminum on Survival of Amphibian Embryos and Larvae. Can. J. Zool. 63:116-123.
- Clark, K.L. and B. LaZerte. 1985. A Laboratory Study of the Effects of Aluminum and pH on Amphibian Eggs and Tadpoles. Can. J. Fish. Aquat. Sci. 42:1544-1551.
- Conroy, N., Hawley, K., Keller, W. and C. Lafrance. 1976. Influences of the Atmosphere on Lakes in the Sudbury Area. Proc. First Spec. Symp. on Atmospheric Assoc. Great Lakes Res. 2:146-165.
- Conroy, N., Hawley, K. and W. Keller. 1978. Extensive Monitoring of Lakes in the Greater Sudbury Area, 1974-76. Ontario Ministry of the Environment Technical Report.
- Conroy, N., Jeffries, D.S. and J.R. Kramer. 1974. Acid Shield Lakes in the Sudbury, Ontario Region. Proceedings of 9th Canadian Symposium on Water Pollution Research in Canada No. 9, pp. 45-61.
- Conroy, N., and W. Keller. 1976. Geological Factors Affecting Biological Activity in Precambrian Shield Lakes. Canadian Mineral 14:62-72.
- Craig, G.R. and W.F. Baksi. 1977. The Effects of Depressed pH on Flagfish Reproduction, Growth and Survival. Wat. Res. 11:621-626.
- deGrosbois, E., Dillon, P.J., Seip, H.M., and H. Seip. 1986. Modelling Hydrology and Sulphate Concentration in Small Catchments in Central Ontario. Wat. Air Soil Pollut. (in press).
- Dillon, P.J. 1984. The Use of Mass Balances and Mass Balance Models for Quantification of the Effects of Anthropogenic Activities on Lakes Near Sudbury, Ontario. pp. 283-347, in Environmental Impacts of Smelters, J. Nriagu, (Ed.), Advances in Environmental Science Series, John Wiley and Sons, Inc.
- Dillon, P.J. 1983. Chemical Alterations of Surface Waters by Acidic Deposition in Canada. Wat. Qual. Bull. 8:127-132.

- Dillon, P.J. and R.D. Evans. 1982. Whole-lake Lead Burdens in Sediments of Lakes in Southern Ontario, Canada. *Hydrobiol.* 91:121-130.
- Dillon, P.J., Jeffries, D.S. and W.A. Scheider. 1982. The Use of Calibrated Lakes and Watersheds for Estimating Atmospheric Deposition Near a Large Point Source. *Wat. Air Soil Pollut.* 18:241-258.
- Dillon, P.J., Jeffries, D.S., Scheider, W.A. and N.D. Yan. 1980. Some Aspects of Acidification in Southern Ontario. p. 212-213, in "Proc. Int. Conf. Ecol. Impact Acid Precip.", Drablos, D. and A. Tollan (Eds.), Norway.
- Dillon, P.J., Jeffries, D.S., Snyder, W., Reid, R., Yan, N.D., Evans, D., Moss, J. and W.A. Scheider. 1978. Acidic Precipitation in South-Central Ontario: Recent Observations. *J. Fish. Res. Board. Can.* 35:809-815.
- Dillon, P.J., Reid, R.A. and R. Girard. 1986. Changes in the Chemistry of Lakes Following Reductions of SO₂ Emissions. *Wat. Air Soil Pollut.* (in press).
- Dillon, P.J. and W.A. Scheider. 1984. Modelling the Reacidification Rates of Neutralized Lakes Near Sudbury, Ontario. pp. 121-154, in Modelling of Total Acid Precipitation Impacts, Schnoor, J.L. (Ed.), Acid Precipitation Series, Volume 9, Ann Arbor Science.
- Dillon, P.J., Scholer, P.J. and H.E. Evans. 1986. Lead-210 Fluxes in Acidified Lakes. *J. Environ. Geol. Wat. Sci.* (in press).
- Dillon, P.J. and P.J. Smith. 1984. Trace Metal and Nutrient Accumulation in the Sediments of Lakes Near Sudbury, Ontario. pp. 375-426, in Environmental Impact of Smelters, Nriagu, J., (Ed.), Advances in Environmental Science Series, John Wiley and Sons, Inc.
- Dillon, P.J., Yan, N.D. and H.H. Harvey. 1984. Acidic Precipitation: Effects on Aquatic Ecosystems. *CRC Critical Reviews in Environmental Control* 13:167-194.
- Dillon, P.J., Yan, N.D., Scheider, W.A. and N. Conroy. 1979. Acidic Lakes in Ontario, Canada: Characterization, Extent and Responses to Base and Nutrient Additions. *Arch. Hydrob. Beih, Ergebn. Limnol.* 13:317-336.
- Ellenton, G., Ley, B.E. and P.K. Misra. 1985. A Trajectory Puff Model of Sulphur Transport for Eastern North America. *Atmospheric Environment* 19:727-737.

- Ellenton, G., Ley, B.E. and P.K. Misra. 1983. Treating Exponential Mass Decay When Wet Scavenging Varies Discreetly Within an Expanding Gaussian Dispersed Puff. The Meteorology of Acid Deposition, Samson, P.J., (Ed.), Proceedings of an APCA Specialty Conference, pp. 528-536.
- Evans, R.D. and P.J. Dillon. 1982. Historical Changes in Anthropogenic Lead Fallout in Southern Ontario, Canada. *Hydrobiol.* 91:131-137
- Evans, H.E., Dillon, P.J., Scholer, P.J. and R.D. Evans. 1986. The use of Pb/²¹⁰Pb ratios in lake sediments for estimating atmospheric fallout of stable lead in south-central Ontario, Canada. *Sci. Tot. Envir.* (in press).
- Evans, H.E., Lasenby, D.C. and P.J. Dillon. 1986. The Effect of Core Compression on the Measurement of Zinc Concentrations and Anthropogenic Burdens in Lake Sediments. *Hydrobiol.* 132:185-192.
- Evans, H.E., Smith, P.J. and P.J. Dillon. 1983. Anthropogenic Zinc and Cadmium Burdens in Sediments of Selected Southern Ontario Lakes. *Can. J. Fish. Aquat. Sci.* 40:570-579.
- Galloway, J.N. and P.J. Dillon. 1983. Effects of Acidic Deposition: The Importance of Nitrogen. Ecological Effects of Acid Deposition. Nat. Swedish Envir. Protection Bd. - Report PM 1636:145-160.
- Glass, G.E. and T.G. Brydges. 1982. Problem Complexity in Predicting Impacts from Altered Precipitation Chemistry. In *Acid Rain/Fisheries*, Johnson, R.E., (Ed.), American Fisheries Society, Bethesda, Md., pp. 265-286.
- Glass, G.E., Leonard, E.N., Chan, W.H. and D.B. Orr. 1986. Airborne Mercury in Precipitation in the Lake Superior Region. *Journal of the International Association for Great Lakes Research* 12:37-51.
- Gunn, J.M. 1986. Behaviour and Ecology of Salmonid Fishes Exposed to Episodic pH Depressions. *Env. Biol. Fish.* (in press).
- Gunn, J.M. and W. Keller. 1985. Effects of Ice and Snow Cover on the Chemistry of Nearshore Lake Water During Spring Melt. *Annals of Glaciology* 7:208-212.
- Gunn, J.M. and W. Keller. 1981. Emergence and Survival of Lake Trout (*Salvelinus namaycush*) and Brook Trout (*S. fontinalis*) from Artificial Substrates in an Acid Lake. Ontario Fisheries Technical Report Series, 1, Toronto.
- Gunn, J.M. and W. Keller. 1980. Enhancement of the Survival of Rainbow Trout (*Salmo gairdneri*) Eggs and Fry in an Acid Lake through Incubation in Limestone. *Can. J. Fish. Aquat. Sci.* 37:1522-1530.

- Gunn, J.M. and W. Keller. 1984. In Situ Manipulation of Water Chemistry Using Crushed Limestone and Observed Effects on Fish. Fisheries 9:19-24.
- Gunn, J.M. and W. Keller. 1984. Spawning Site Water Chemistry and Lake Trout (Salvelinus namaycush) Sac Fry Survival During Spring Snowmelt. Can. J. Fish. Aquat. Sci. 42:319-329.
- Gunn, J.M. and W. Keller. 1986. Effects of acidic meltwater on chemical conditions at nearshore spawning sites. Wat. Air Soil Pollut. (in press).
- Harvey, H.H., Pierce, R.C., Dillon, P.J., Kramer, J.P. and D.M. Whelpdale. 1981. Acidification in the Canadian Aquatic Environment. Publ. NRCC No. 18475 of the Environment Secretariat, National Research Council, Canada.
- Heidorn, K.C. and D. Yap. 1986. A Synoptic Climatology for Surface Ozone Concentrations in Southern Ontario, 1976 - 1981. Atmospheric Environment 20:695-703.
- Hendry, G.R., Yan, N.D. and K.J. Baumgartner. 1980. Responses of Freshwater Plants and Invertebrates to Acidification. pp. 457-466. In "Restoration of Lakes and Inland Waters". Proc. Symp. 8-12 September 1980. Portland, Maine, U.S.A. EPA 440 15-81-010.
- Jeffries, D.S. 1984. Atmospheric Deposition of Pollutants in the Sudbury Area. pp. 117-154, in Environmental Impacts of Smelters, Nriagu, J., (Ed.), Advances in Environmental Impacts of Science Series, John Wiley and Sons, Inc.
- Jeffries, D.S., Cox, C.M. and P.J. Dillon. 1979. Depression of pH in Lakes and Streams in Central Ontario During Snowmelt. J. Fish. Res. Board. Can. 36:640-646.
- Jeffries, D.S., Scheider, W.A. and W.R. Snyder. 1984. Geochemical Interactions of Watersheds with Precipitation in Areas Affected by Smelter Emissions Near Sudbury, Ontario. pp. 195-241, in Environmental Impacts of Smelters, Nriagu, J., (Ed.), Advances in Environmental Science Series, John Wiley and Sons, Inc.
- Jeffries, D.S. and W.R. Snyder. 1981. Atmospheric Deposition of Heavy Metals in Central Ontario. Wat. Air Soil Pollut. 15:127-152.
- Jeffries, D.S. and W.R. Snyder. 1981. Variations in Chemical Composition of the Snowpack and Associated Melt-waters in Central Ontario. Proc. 38th Eastern Snow Conference, New York.
- Jeffries, D.S., Snyder, W.R., Scheider, W.A. and M. Kirby. 1978. Small-Scale Variations in Precipitation Loading Near Dorset, Ontario. Wat. Poll. Res. Can. 13:73-84.

- Jeffries, D.S., and A.P. Zimmerman. 1980. Comments on the Analysis and Sampling of Low Conductivity Natural Waters for Alkalinity. *Can. J. Fish. Aquat. Sci.* 37:901-902.
- Keller, W. 1978. Limnological Observations on the Aurora Trout Lakes. Ontario Ministry of the Environment Technical Report. 49 pages.
- Keller, W. 1981. Planktonic Crustacea in Lakes in the Greater Sudbury Area. Ontario Ministry of the Environment Technical Report. 33 pages plus appendices.
- Keller, W. 1983. Spring pH and Alkalinity Depressions in Lake Superior Tributaries. *J. Great Lakes Res.* 9:425-429.
- Keller, W., Gunn, J. and N. Conroy. 1980. Acidification Impacts on Lakes in the Sudbury, Ontario, Canada Area. *Proc. Int. Conf. on the Ecological Impact of Acid Precipitation, Sandefjord, Norway.* pp 228-229.
- Keller, W. and J.R. Pitblado. 1984. Crustacean Plankton in Northeastern Ontario Lakes Subjected to Acidic Deposition. *Wat. Air Soil Poll.* 23:271-291.
- Keller, W. and J.R. Pitblado. 1986. Water quality changes in Sudbury area lakes: A comparison of synoptic surveys in 1974-76 and 1981-83. *Wat. Air Soil Pollut.* 29:285-296.
- Keller, W., Pitblado, J.R. and N.I. Conroy. 1986. Water quality changes in the Sudbury, Ontario, Canada area related to reduced smelter emissions. *Wat. Air Soil Pollut.* (in press).
- Kuja, A.L. and A.J. Enyedi. 1983. Effect of Simulated Acid Rain on Agricultural Crops. *Proceedings Agrometeorological Workshop, University of Guelph,* pp. 82-83.
- Kurtz, J. and W.A. Scheider. 1981. An Analysis of Acidic Precipitation in South-Central Ontario Using Air Parcel Trajectories. *Atm. Environ.* 15:1111-1116.
- Kurtz, J., Tang, A.J., Kirk, R.W. and W.H. Chan. 1983. Analysis of an Acidic Deposition Episode at Dorset, Ontario. Accepted for publication in *Atmospheric Environment*.
- LaZerte, B.D. 1986. Metals and Acidification: An Overview. *Wat. Air Soil Pollut.* (in press).
- LaZerte, B.D. 1984. Forms of Aqueous Aluminum in Acidified Catchments of Central Ontario: A Methodological Analysis. *Can. J. Fish. Aquat. Sci.* 41:766-776.

- LaZerte, B.D. and P.J. Dillon. 1984. Relative Importance of Anthropogenic Versus Natural Sources of Acidity in Lakes and Streams of Central Ontario. Can. J. Fish. Aquat. Sci. 41:1664-1677.
- Linzon, S.N., Pearson, R.G., Gizyn, W.I. and M.A. Griffith. 1981. Terrestrial Effects of Long Range Pollutants on Crops and Soils. Proceedings Air Pollution Control Association. Ontario and Quebec Sections. Joint Meeting on Acid Deposition, Montreal, Quebec, 17 pp.
- Linzon, S.N. and P.J. Temple. 1980. Soil Resampling and pH Measurements After an 18-Year Period in Ontario. Proc. In Conf. on the Ecological Impact of Acid Precipitation, Sandefjord, Norway, pp. 176-177.
- Lusis, M.A. 1982. Measurement Techniques for Acidic Airborne Constituents. Presentation at the Symposium on Monitoring and Assessment of Airborne Pollutants with Special Emphasis on Long-Range Transport and Deposition of Acidic Materials, National Research Council of Canada, Ottawa, Ontario, August 30 - September 1, 1982.
- Lusis, M.A., Chan, W.H., Misra, P.K., Voldner, E.C., Vet, R.J., Olsen, A.R., Bigelow, D. and T.L. Clark. 1986. A Unified Wet Deposition Data Base for Eastern North American - Data Screening and Calculation Procedures and Results. Presented at the Annual Meeting of the Air Pollution Control Association, Minneapolis, June 22-27, 1986.
- Lusis, M.A., Chan, W.H., Tang, A.J. and N.D. Johnson. 1983. Scavenging Rates of Sulphur and Trace Metals from a Smelter Plume. Proceedings, 4th International Conference on Precipitation Scavenging, Dry Deposition and Resuspension. Slinn, E.G. (Ed.), Elsevier Science Publishing Co. Inc.
- Lusis, M.A., Chan, W.H., Tang, A.J. and R.W. Kirk. 1983. Wet and Dry Deposition of Sulphur and Nitrogen Compounds on a Regional Scale: Results from the Ontario Network for 1982. CACGP Symposium on Tropospheric Chemistry, August 28 - September 3, Oxford.
- Lusis, M.A., Sahota, H., Yap, D. and N. Reid. 1987. Oxidant Formation and Transport from Petrochemical Complex Emissions in Ontario. Presented at the North American Oxidant Symposium, Quebec City, February 25-27, 1987.
- Lusis, M.A. and L. Shenfeld. 1981. The Seasonal Dependence of Atmospheric Deposition and Chemical Transformation Rates for Sulphur and Nitrogen Compounds. Report No. ARB-08-ARSP.
- MacIsaac, H.J., Keller, W., Hutchinson, T.C. and N.D. Yan. 1986. Natural Changes in Planktonic Rotifera of a Small Acid Lake near Sudbury, Ontario Following Water Quality Improvements. Wat. Air Soil Pollut. (in press).

- Matuszek, J.E. 1986. Fish species richness in relation to pH in Ontario Lakes. J. Fish. Aquat. Sci. (in press).
- McBean, E.A. and Associates Ltd. 1983. Linear Programming Screening Model for Development and Evaluation of Acid Rain Abatement Strategies. Toronto: Policy and Planning Branch, Ontario Ministry of the Environment.
- McBean, E.A. and Associates Ltd. 1983. Linear Programming Screening Model for Development and Evaluation of Acid Rain Abatement Strategies. Appendix I: "Mathematical Model Documentation of DATAGEN". Toronto: Policy and Planning Branch, Ontario Ministry of the Environment.
- McBean, E.A. and Associates Ltd. 1983. Linear Programming Screening model for Development and Evaluation of acid Rain Abatement Strategies. Appendix II: "Development of SO₂ Emission Control Costs". Toronto: Policy and Planning Branch, Ontario Ministry of the Environment.
- McBean, E.A. and Associates Ltd. 1983. Linear Programming Screening Model for Development and Evaluation of Acid Rain Abatement Strategies. Appendix III: "Canadian Source Inventory". Toronto: Policy and Planning Branch, Ontario Ministry of the Environment.
- McLaughlin, D.L., Linzon, S.N., Dimma, D.E. and W.D. McIlveen. 1985. Sugar Maple Decline in Ontario. Interim Report, 18 pp.
- McQuaker, N.R., Kluckner, P.D., Torneby, J.E., Sorbara, S.E., Chan, W.H. and M.E. Still. 1982. Standard Methods for National Wet-Only Precipitation Sampling and Chemical Analysis. A Joint Report with the Federal and other Provincial Governments.
- Mierle, G. 1985. Kinetics of Phosphate Transport by Synechococcus leopoliensis: Evidence for Diffusion Limitation of Phosphate Uptake. J. Phycol. 21:177-181.
- Mierle, G. 1985. A Method for Estimating the Diffusion of Resistance of the Unstirred Layer of Microorganisms. Biochim. Biophys. Acta. 812:827-834.
- Mierle, G. 1985. The Effect of Cell Size and Shape in the Resistance of Unstirred Layers to Solute Diffusion. Biochimica et Biophysica Acta. 812:835-839.
- Mierle, G., Clark, K. and R. France. 1986. The Impact of Acidification on Aquatic Biota in North America: A Comparison of Field and Laboratory Results. Wat. Air Soil Pollut. (in press).
- Millan, M.M., Barton, S.C., Johnson, N.D., Weisman, B., Lusi, M.A., Chan, W. and R. Vet. 1982. Rain Scavenging from Tall Stack Plumes: A New Experimental Approach. Atmospheric Environment 16:2709-2714.

- Miller, G.E., Wile, I. and G. Hitchin. 1983. Patterns of Accumulation of Selected Metals in Members of the Soft-water Macrophyte Flora of Central Ontario Lakes. *Aquat. Botany* 15:53-64.
- Minns, C.K. 1986. Analysis of the Ontario Lake Inventory Data Base I and a Model of Biases in Lake Selection and II Fish Species Community Structure in Ontario Lakes. *Ont. Fish. Tech. Rep. Sci.* (in press).
- Misra, P.K., Chan, W.H., Chung, D. and A.J.S. Tang. 1985. Scavenging Ratios of Acidic Pollutants and Their Use in Long Range Transport Models. *Atmospheric Environment* 19:1741-45.
- Nicholls, K.H. 1978. Chrysochromulina breviturrita sp. nov., a New Freshwater Member of the Prymnesiophyceae. *J. Phycol.* 14:499-505.
- Nicholls, K.H. 1987. The identification of some Mallomonas species of the M. doignonii group (Chrysophyceae). *Nord. J. Bot.* (in press).
- Nicholls, K.H. 1987. The distinction between Mallomonas acaroides var. acaroides and Mallomonas acaroides var. muskokana var. nov. (Chrysophyceae). *Can. J. Bot.* (in press).
- Nicholls, K.H. 1987. Descriptions of three new species of Mallomonas (Chrysophyceae): M. hexagonis., M. liturata., and M. galeiformis. *Br. Phycol. J.* (in press).
- Nicholls, K.H. 1987. Form variation in Mallomonas asmundiae and a description of Mallomonas sphagniphila sp. nov. Series Corconticae, (Mallomonadaceae). *Can. J. Bot.* 65:627-634.
- Nicholls, K.H. 1987. Variation in silica scale morphology Mallomonas pseudocoronata (Chrysophyceae). *Nord. J. Bot.* 7 (in press).
- Nicholls, K.H. 1987. Additions to the Mallomonas (Chrysophyceae) flora of Ontario, Canada and a checklist of North American Mallomonas species. *Can. J. Bot.* (in press).
- Nicholls, K.H., Beaver, J.L. and R.H. Estabrook. 1982. Lakewide Odours in Ontario and New Hampshire Associated with Chrysochromulina breviturrita Nich. (Prymnesiophyceae). *Hydrobiol.*
- Nicholls, K.H. and C. Cox. 1978. Atmospheric Nitrogen and Phosphorus Loading to Harp Lake, Ontario, Canada. *Water Resources Res.* 14:589-592.

- Orr, D.B., Hipfner, J.C., Chan, W.H., Lusi, M.A. and J.E. Hunt. 1987. The Application of a Passive Permeation Device for the Measurements of Ambient Sulfur Dioxide. Atmospheric Environment (in press).
- Pitblado, J.R. and W. Keller. 1984. Data Report - Monitoring of Northeastern Ontario Lakes, 1981-83. Ontario Ministry of the Environment Technical Report. 9 pages plus appendices.
- Pitblado, J.R., Keller, W. and N. Conroy. 1980. A Classification and Description of some Northeastern Ontario Lakes Influenced by Acid Precipitation. J. Great Lakes Res. 6:247-257.
- Ruby, S.M., Aezel, J. and G.R. Craig. 1977. The Effects of Depressed pH on Oogenesis in Flagfish Jordanella floridae. Wat. Res. 11:757-762.
- Ruby, S.M., Aezel, J. and G.R. Craig. 1978. The Effects of Depressed pH on Spermatogenesis in Flagfish Jordanella floridae. Wat. Res. 12:621-626.
- Rustad, S., Christophersen, N., Seip, H.M. and P.J. Dillon. 1986. A Model for Streamwater Chemistry in a Tributary to Harp Lake, Ontario. Can. J. Fish. Aquat. Sci. (in press).
- Scheider, W.A. 1984. Lake Water Budgets in Areas Affected by Smelting Practices Near Sudbury, Ontario. pp. 155-194, in Environmental Impacts of Smelters, Nriagu, J., (Ed.), Advances in Environmental Science Series, John Wiley and Sons, Inc.
- Scheider, W.A. and T.G. Brydges. 1984. Whole-Lake Neutralization Experiments in Ontario: A Review. Fisheries 9:17-18.
- Scheider, W.A. and P.J. Dillon. 1983. Predicting Chemical and Physical Effects of Acidic Deposition on Aquatic and Terrestrial Ecosystems - Information Needs. Proc. Symp. Monitoring and Assessment of Airborne Pollutants. Nat. Res. Council Canada. NRCC No. 20642:84-114.
- Scheider, W.A., Jeffries, D.S. and P.J. Dillon. 1981. Bulk Deposition in the Sudbury and Muskoka-Haliburton Areas of Ontario During the Shutdown of Inco Ltd., in Sudbury. Atm. Environ. 15:945-956.
- Scheider, W.A., Jeffries, D.S. and P.J. Dillon. 1979. Effects of Acidic Precipitation on Precambrian Freshwaters in Southern Ontario. J. Great Lakes Res. 5:45-51.

- Scheider, W.A., Locke, B.A., Nicolls, A.C. and R.E. Girard. 1985. Snowpack and Streamwater Chemistry in Three Watersheds in Muskoka-Haliburton, Ontario. Proc. Can. Hydrology Symp., 10-12 June, 1984. Quebec City, Quebec (in press).
- Scheider, W.A., Locke, B.A., Nicolls, A.C. and R.E. Girard. 1985. Snowpack and Streamwater Chemistry in Three Watersheds in Muskoka-Haliburton, Ontario. Proc. Can. Hydrology Symp., 10-12 June, 1984. Quebec City, Quebec (in press).
- Scheider, W.A., Logan, L.A., Belore, H.S. and R.C. MacRae. 1985. Simulation of Snowmelt and Streamflow During Spring Runoff in Muskoka-Haliburton, Ontario. Proc. Can. Hydrology Symp., 10-12 June, 1984, Quebec City, Quebec :83-108.
- Scheider, W.A., Logan, L.A. and M.G. Goebel. 1983. A Comparison of Two Models to Predict Snowmelt in Muskoka-Haliburton, Ontario. pp. 157-168, in Proc. 40th Eastern Snow Conference, June 2-3, 1983, Toronto.
- Scheider, W.A., Snyder, W.R. and B. Clark. 1979. Deposition of Nutrients and Ions by Precipitation in South-Central Ontario. Wat. Air Soil Pollut. 12:171-185.
- Schiermeier, F.A. and P.K. Misra. 1983. Evaluation of Eight Linear Regional Scale Sulphur Models by the Regional Modelling Subgroup of the United States-Canada Memorandum of Intent Work Group 2. The Meteorology of Acid Deposition, Samson, P.J., (Ed.), Proceedings of an APCA Specialty Conference, pp. 330-345.
- Schut, P.H., Evans, R.D. and W.A. Scheider. 1986. Variation in Trace Metal Exports from Small Canadian Shield Watersheds. Wat. Air Soil Pollut. (in press).
- Seip, H.M. and P.J. Dillon. 1984. Acid Rain and Soil Chemistry. Science 225:1425-1426.
- Seip, H.M., Seip, R., Dillon, P.J. and E. de Grosbois. 1985. Model of Sulphate Concentration in a Small Stream in the Harp Lake Catchment, Ontario. Can. J. Fish. Aquat. Sci. 42:927-937.
- Suns, K., Curry, C. and D. Russell. 1980. Effects of Water Quality and Morphometric Parameters on Mercury Uptake by Yearling Yellow Perch. Ontario Ministry of the Environment Technical Report LTS 80-1, 16 pp.
- Tang, A.J.S., Chan, W.H., Chung, D.H.S. and M.A. Lusi. 1986. Spatial and Temporal Variability of Precipitation Concentration and Wet Deposition of Acidic Pollutants in Ontario. Water, Air and Soil Pollution (in press).

- Tang, A.J.S., Yap, D., Kurtz, J., Chan, W.H. and M.A. Lusi. 1986. An analysis of the Impact of the Sudbury Smelters on Wet and Dry Deposition in Ontario. Atmospheric Environment (in press).
- Tung, G., Kuja, A.L. and S.N. Linzon. 1982. Histopathology of Plant Leaf Injury Caused by Simulated Acid Rain. Proceedings of Microscopical Society of Canada, Vol IX, Univ. Alberta, pp. 64-65.
- Turner, M.A., Jackson, M.B., Findlay, D.K., Graham, R.W., De Bruyn, E.R. and E.M. Vandermeer. 1987. Early Response of Periphyton to Experimental Lake Acidification. Can. J. Fish. Aquat. Sci. 44(Supl. 1):135-149.
- Venkatram, A. 1982. Short Range Short-term Fumigation Model for the Inco Superstack. Report #SES 013/82.
- Venkatram, A., Ley, B. and S.Y. Wong. 1982. A Statistical Model to Estimate Long-Term Concentrations of Pollutants Associated with Long-Range Transport and its Application to Emissions from the Sudbury Region. Report #ARB-36-81-SES.
- Vet, R.J., Chan, W.H. and M.A. Lusi. 1981. An Intercomparison Study of Three Sampling Networks in Ontario - APIOS, CANSAP and GLPN. Report No. ARB-002-81-ARSP.
- Wile, I., Miller, G.E., Hitchin, G.G. and N.D. Yan. 1985. Species Composition and Biomass of the Macrophyte Vegetation of One Acidified and Two Acid Sensitive Lakes in Ontario. Can. Field Nat. 99:308-312.
- Wong, S.L. 1980. Algal Bioassays to Determine Toxicity of Metal Mixtures. Hydrobiol. 74:199-208.
- Wright, R.F., Conroy, N., Dickson, W.T., Harriman, R., Henricksen, A. and C.L. Schofield. 1980. Acidified Lake Districts of the World: A Comparison of Water Chemistry of Lakes in Southern Norway, Southern Sweden, Southwestern Scotland, the Adirondack Mountains of New York and Southeastern Ontario. Proc. Int. Conf. on the Ecological Impact of Acid Precipitation, Sandefjord, Norway, pp. 377-379.
- Yan, N.D. 1986. Empirical Prediction of Crustacean Zooplankton Biomass in Nutrient-poor Canadian Shield Lakes. Can. J. Fish. Aquat. Sci. 43:788-796.
- Yan, N.D. 1983. The Effects of Changes in pH on Transparency and Thermal Regimes of Lohi Lake, Near Sudbury, Ontario. Can. J. Fish. Aquat. Sci. 40:621-626.

- Yan, N.D. 1980. Acid Rain: A Progress Report. In Gulston, C.L. (Ed.). Perspectives in Natural Resources. Symposium III: Water. 6-8 November, 1980. Lindsay, Ont. pp. 95-114.
- Yan, N.D. 1979. Phytoplankton of an Acidified Heavy Metal Contaminated Lake Near Sudbury, Ontario; 1973-1977. Water Air Pollut. 11:43-55.
- Yan, N.D. and P.J. Dillon. 1984. Experimental Neutralization of Lakes Near Sudbury, Ontario. pp. 417-456, in Environmental Impacts of Smelters, Nriagu, J. (Ed.), Advances in Environmental Science Series, John Wiley and Sons, Inc.
- Yan, N.D. and W. Geiling. 1985. Elevated Planktonic Rotifer Biomass in Acidified, Metal-Contaminated Lakes Near Sudbury, Ontario. Hydrobiol. 120:199-205.
- Yan, N.D. and R. Girard. 1986. Delayed Recovery of Zooplankton Communities of Acidic, Metal-Contaminated Lakes Near Sudbury, Ontario Following Improvements in Water Quality. Can. J. Fish. Aquat. Sci. (in press).
- Yan, N.D. and C. Lafrance. 1984. Responses of Acidic Neutralized Lakes Near Sudbury, Ontario to Nutrient Enrichment. pp. 457-521, in Environmental Impacts of Smelters, Nriagu, J. (Ed.), Advances in Environmental Science Series, John Wiley and Sons, Inc.
- Yan, N.D., Lafrance, C.J. and G.G. Hitchin. 1982. Planktonic Fluctuations in a Fertilized, Acidic Lake: The Role of Invertebrate Predators. In Proceedings of an International Symposium on Acidic Rain and Fishery Impacts on Northeastern North America. Cornell Univ., Ithaca, N.Y., August 2-5, 1981, pp. 137-154.
- Yan, N.D. and G.E. Miller. 1984. Effects of Deposition of Acids and Metals on Chemistry and Biology of Lakes Near Sudbury, Ontario. pp. 243-282, in Environmental Impacts of Smelters, Nriagu, J. (Ed.), Advances in Environmental Science Series, John Wiley and Sons, Inc.
- Yan, N.D., Miller, G.E., Wile, I. and G.G. Hitchin. 1985. Richness of Aquatic Macrophyte Floras of Soft Water Lakes of Differing pH and Trace Metal Content in Ontario, Canada. Aquatic Botany 23:27-40.
- Yan, N.D., Nero, R.W., Keller, W. and D.C. Lasenby. 1985. Are Chaoborus Larvae More Abundant in Acidified Lakes in Central Canada? Holartic Ecology 8:93-99.
- Yan, N.D., Scheider, W.A. and P.J. Dillon. 1977. Chemical and Biological Changes in Nelson Lake, Ontario, Following Experimental Elevation of Lake pH. Wat. Pollut. Res. Can. 12:213-231.

- Yan, N.D. and P. Stokes. 1978. Phytoplankton of an Acidic Lake and its Responses to Experimental Alterations of pH. Environ. Conservat. 5:93-100.
- Yan, N.D. and R. Strus. 1980. Crustacean Zooplankton Communities of Acidic, Metal-Contaminated Lakes Near Sudbury, Ontario. Can. J. Fish. Aquat. Sci. 37:2282-2293.
- Yap, D. and J. Kurtz. 1986. Meteorological Analyses of Acidic Precipitation in Ontario. Water, Air and Soil Pollution 30:873-878.



(6916)

TD/196/A25 A32/1986-87/MOE

APIOS